

Essentials of Oral Histology

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Essentials of Oral Histology

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JAYPEE BROTHERS

MEDICAL PUBLISHERS (P) LTD

New Delhi

Published by

Jitendar P Vij

Jaypee Brothers Medical Publishers (P) Ltd

B-3 EMCA House, 23/23B Ansari Road, Daryaganj, **New Delhi** 110 002, India

Phones: +91-11-23272143, +91-11-23272703, +91-11-23282021, +91-11-23245672, Rel: 32558559

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Essentials of Oral Histology

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First Edition: 2006

ISBN 81-8061-865-X

Typeset at JPBMP typesetting unit

Printed at Gopsons Papers Ltd, A-14, Sector 60, Noida 201 301, India

To
My parents
Dr Kamal Bose
and
Ashoka Bose

Preface

The oral cavity or stomatodeum is considered as the mirror of the body. Many systemic diseases have their oral manifestations. So a good clinician should have a firm knowledge of Oral Histology which is the fundamental science for understanding the intricate morphologies of oral and paraoral tissues.

There are several excellent textbooks available on Oral Histology. *Essentials of Oral Histology* has been written with a view to present the subject to the undergraduate dental students in a more simplified manner for their easy assimilation. It is a humble attempt to fill the niche for the students of dentistry with the current information about the development, structure and function of teeth and associated tissues.

I assume all the responsibilities for errors and omissions in this book. I sincerely welcome the constructive suggestions from the students and the teachers for further improvement of this maiden effort.

Kabita Chatterjee

Acknowledgements

I take this opportunity to express my deep sense of gratitude to Dr HM Dholakia, Dr BB Dutta, Dr KL Banerjee, Dr DL Koley, Dr KS Roy Chowdhury, Dr S Talukdar and Dr RR Pal for teaching me with their personal attention and valuable guidance.

It is my proud privilege to thank my friends, colleagues and students for their continuous encouragement.

I gratefully acknowledge the help of my aunt Miss Sati Mitra for typing the manuscript.

Special thanks and appreciation are extended to my husband Dr DK Chattopadhyay and son Dipmalya Chatterjee for drawing the figures.

I am deeply indebted to all the authors who have contributed to my knowledge of Oral Histology.

I extend my warm regards to my publisher and distributor for their support and enthusiasm.

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1

Histological Techniques for Study of Oral Tissues

Histology (Gr. Histo—tissue + logos— study) is the study of tissues. It is a science based on the ability to recognize the architectural patterns and cytomorphology of normal tissues.

Oro-dental tissue comprises of oral mucous membrane, three pairs of major and innumerable minor salivary glands, jaw bones with deciduous and permanent sets of dentitions, maxillary sinus and temporomandibular joint. The teeth are composed of following tissues (Fig. 1.1).

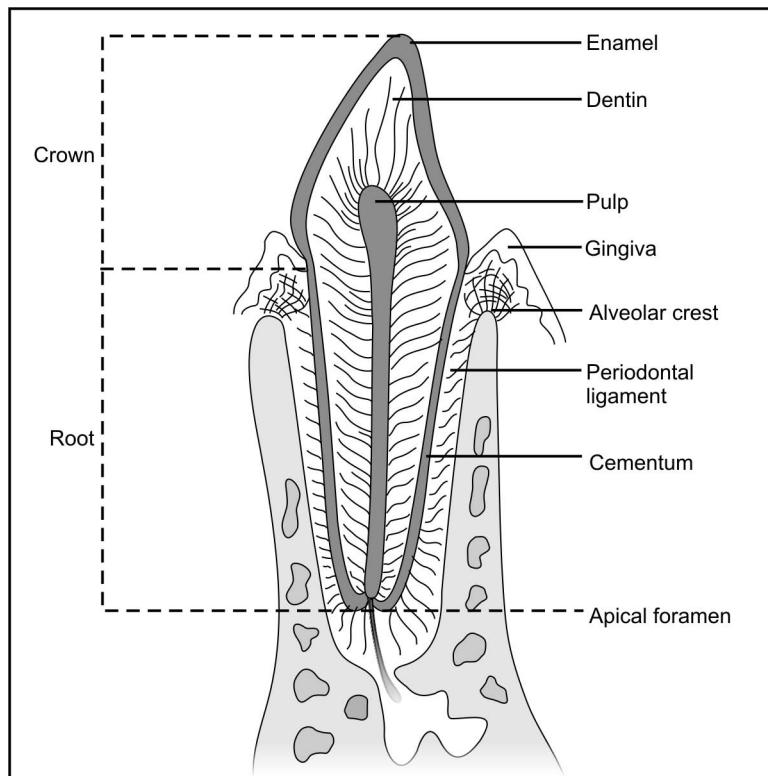


Fig. 1.1: Parts of a tooth

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- A. Enamel—It is the hardest tissue in human body, covering the crown of the tooth.
- B. Dentin—It is the calcified tissue forming the main bulk of the tooth. In crown portion, it is covered by the enamel and in the root portion it is covered by the cementum.
- C. Cementum—It is the calcified tissue covering the radicular portion of the tooth.
- D. Pulp—It is the soft, delicate tissue in the innermost core of the tooth, surrounded by hard shell of dentin, enamel and cementum.
- E. Periodontium—The tissues (periodontal ligament, cementum, alveolar bone) which support the teeth in jaws are collectively termed periodontium.

The small size of the cells and matrix components make histology dependent on the use of the microscopes.

1. Microscopy

- a. *Light Microscopy*—Different types of light microscopes are available for the study of tissues.

Bright-field Microscope—This is a complex, optical instrument which uses visible light. This is the most commonly used microscope. The specimen to be viewed with this microscope needs to be sufficiently thin so that the light can pass through it. The usefulness of this light microscope is its ability to magnify and, more importantly, its ability to resolve structural detail.

Dark Ground Illumination—This method allows only that light which is scattered at the periphery of the specimen. It is mainly used for the study of the spirochetes which look like bright objects against a dark background.

Phase Contrast Microscope—It is used for the examination of unstained specimens especially living cells from body or tissue culture.

Fluorescence Microscope—The fluorescence microscope detects molecules which are fluorescent, i.e. emit light of wavelengths in the visible range when exposed to an ultraviolet light source. It is used in the detection of the antigens and antibodies in immuno-cytochemical staining procedure and also in detecting fluorescent growth markers of the mineralized tissues.

Confocal Scanning Microscope—This microscope is used to study the structure of the biological material.

Ultraviolet Microscope—This microscope uses an ultraviolet light source and depends on the absorption of ultraviolet light by the molecules in the specimen. This method is useful for detecting nucleic acid.

Polarizing Microscope—The polarizing microscope is a simple modification of the light microscope in which polarized light is passed through the specimen and another polarizer is used as a rotator to detect molecular orientation within a tissue sample. Crystalline substances and well-ordered fibrous molecules alter the plane of the entering polarized light and altered plane of light is noted with the detector lens. The rotation of polarized light due to the molecular orientation of tissue components is referred to as birefringence. Enamel, dentin and cemental tissues show birefringence under polarized light.

- b. *Electron Microscopy*

Transmission Electron Microscope (TEM)—The TEM utilizes a beam of electrons instead of light in producing an image. It involves the passage of a high-velocity homogeneous electron beam through a specimen that is thin enough to transmit at least 50% of the

incident electrons. The emergent beam of transmitted electrons is then referred by a system of lenses to form a magnified, two-dimensional image of the specimen.

Scanning Electron Microscope (SEM)—Scanning electron microscopy differs from transmission electron microscopy in that the electrons do not pass through the specimen as part of the image-making process. Instead a beam of electrons is made to scan the surface views. The inside of organs can be analyzed by freezing the organs and fracturing them to expose their internal surfaces.

2. Few Analytical Methods

Autoradiography—It is the study of the biological events in the tissue sections using radioactivity. Various informations like divisions of cells, site of protein synthesis, pathway of migration of cell, etc. can be obtained by autoradiography.

Historadiography—It is actually the production of an X-ray photograph, that is, microradiograph of a specimen on a slide. It is used for quantitative analysis of bone or other mineralized tissues.

Cell and tissue culture—Live cells and tissues can be maintained and studied outside the body. Cell culture has been widely used for the study of the metabolism of normal and cancerous cells, for the development of new drugs and for the study of chromosomes.

Histochemistry and cytochemistry—The terms histochemistry and cytochemistry are used mainly to indicate methods for localizing different substances in tissue section. The procedures are based on specific chemical reactions or on high-affinity interactions between macromolecules. These methods usually produce insoluble colored or electron dense compounds that enable the localization of specific substances by means of light or electron microscopy.

ROUTINE LABORATORY TECHNIQUES FOR HISTOLOGIC STUDY

There are different procedures for preparation of tissues for microscopic examination—

1. Paraffin embedding.
2. Frozen section.
3. Parlodion embedding.
4. Ground section.

Paraffin Embedding Procedure

Indication—This is the most commonly used method of preparing tissues for routine sectioning and staining.

Procedure

Obtaining the specimen—

- The specimen is surgically removed with minimum trauma.
- Blood clot is removed under running tap water.

Fixation of Specimen

- The specimen is fixed in 10 % neutral formalin for 24 hours.
- The fixative solution will coagulate the proteins and preserve the tissue.

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- It prevents alteration of tissues by subsequent treatment.
- It makes tissue more readily permeable to the subsequent applications of reagent.
- After fixation, the specimen is washed overnight in running tap water.

Dehydration of the Specimen

- The specimen is gradually dehydrated in ascending grades of alcohol (40%, 60%, 80%, 95% and absolute alcohol), one hour in each strength.
- The specimen is dehydrated as the subsequent infiltration and embedding are done in molten paraffin which is not miscible with water.

Clearing

- The paraffin is also not miscible with the alcohol. So the alcohol is removed from the specimen by placing it in two changes of xylene, one hour in each.
- Xylene is miscible with both alcohol and paraffin.
- The specimen appears transparent after xylene treatment, hence the name of the step is clearing.

Infiltration of the Specimen with Paraffin

- As alcohol in the tissue is totally replaced by xylene, the specimen is ready to be infiltrated in paraffin.
- From xylene the tissue is placed in three changes of molten paraffin at 60°C in hot air oven, one hour in each.

Embedding the Specimen

- After infiltration, the tissue is embedded in the center of a block of paraffin.
- Two L- shaped brass pieces [Leuckhard L- pieces] are adjusted to a required size and shape on a metal platform and is filled with molten paraffin.
- The infiltrated tissue is taken from molten paraffin with a warm forceps and is placed in the center of the box of paraffin with the surface to be cut first toward the bottom of the box.
- The hardened paraffin block is removed, trimmed so that there is about 3 mm of paraffin surrounding the specimen on all four sides and fixed on a wooden block.

Cutting Sections

- The wooden cube to which the paraffin block is attached is clamped on a precision rotary microtome (Fig.1.2).
- The microtome is adjusted to cut sections of the desired thickness (usually 4 to 10 μm) and the perfectly sharpened microtome knife is clamped into place for sectioning.
- The sections are placed on warm water bath to spread flat. It is transferred on glass slide, smeared with a mixture of egg albumin in glycerine and placed on a hot air oven at 42°C for adhering the tissues to the slides.

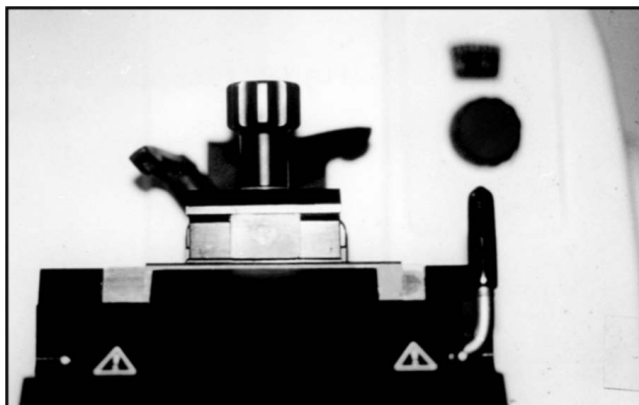


Fig. 1.2: Precision rotary microtome

Staining the Sections

- Paraffin is removed from the section by xylene, which is removed by absolute alcohol and the section is brought back to water by treatment with descending grades of alcohol followed by placing it under running tap water.
- The slide is placed in hematoxylin for 5-10 minutes to stain nuclei.
- The section is then placed in distilled water to rinse off excess stain.
- The section is differentiated in ammonium alum.
- Then dipped in eosin solution for 1 minute to stain cytoplasm and intercellular substance.
- The section is washed with distilled water, treated with ascending grades of alcohol, cleared with xylene, mounted with D.P.X. and coverglass is affixed.
- After the mounting medium hardens, the slides are ready for examination.

Preparation of Frozen Sections

The fresh, unfixed, or fixed soft tissue may be frozen and sectioned without being embedded. Such tissue sections are usually referred to as frozen sections.

Indications

1. It is useful if the immediate examination of a specimen is required.
2. It is also useful when the tissue characteristics to be studied would be destroyed by the reagents used in paraffin embedding.

A block of fixed or unfixed soft tissue is frozen with either liquid or solid carbon-di-oxide. Sections are taken from frozen tissue in a freezing microtome having 10-15 μ m thickness.

Preparation of Sections of Parlodion Embedded Specimens

Indications

To examine

1. The delicate pulp tissue, periodontal ligament along with dentin and cementum;

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2. Bone with bony matrix; tooth and bone specimens are to be decalcified and embedded in parlodion as it is very difficult to get good sections if they are embedded in paraffin.

Procedure

1. Obtaining the specimen.
2. Fixation in 10% neutral formalin for a week
3. Decalcification in any of the following solution.
 - a. 5% Nitric acid
 - b. 5% Formic acid
 - c. Mixture of Potassium formate and Formic acid.

The specimen is suspended in any of the solution for several days and the solution is changed everyday till there is complete decalcification. The specimen may be X-rayed from time to time, a needle may be inserted through the specimen or the solution may be tested chemically to determine the extent of decalcification.

4. Washing the specimen in running tap water for several hours to remove all of the acid.
5. Dehydration in ascending grades of alcohol. Then specimen is changed to 1:1 proportion of ether and absolute alcohol. (as parlodion is dissolved in ether alcohol).
6. Infiltration of the specimen with parlodion.
7. Embedding the specimen in parlodion.
8. Cutting the sections of specimen—The sections are cut in a precision sliding microtome at a thickness of 15 μm .

Staining the sections: The sections are first stained with hematoxylin and eosin and then mounted on a slide.

Preparation of Ground Sections of Teeth or Bone

Indications

1. Enamel is studied histologically only by ground section as it contains 96% of inorganic material.
2. Inorganic component of dentin, cementum and bone may be studied by making thin ground sections.

Equipments

- a. A laboratory lathe
- b. A coarse and a fine abrasive lathe wheel
- c. A stream of water directed onto the rotating wheel
- d. A pan beneath to catch the water
- e. A wooden block (25 mm cube)
- f. 13 mm adhesive tape
- g. A camel's hair brush
- h. Ether
- i. Mounting medium
- j. Microscope
- k. Cover glasses.

Procedure

- The tooth or bone with the desired plane of section is held securedly in the fingers and is applied firmly to the flat surface of rapidly rotating coarse abrasive wheel (Fig. 1.3). Water is directed constantly onto the wheel to prevent charring. The tooth is ground down nearly to the level of the desired section.



Fig. 1.3: Laboratory lathe

- The coarse wheel is now exchanged for a fine abrasive lathe wheel, and the cut surface of the tooth is ground again until the level of the desired section is reached.
- At this point the section of tooth is pressed onto the wooden block by means of adhesive tape and ground down to a thickness of about 0.5 mm.
- Then fine-abrasive lathe wheel is used for thinner section.
- Then specimen is now rubbed on a ground glass with pumice-glycerine paste to remove the scratches on the tooth.
- The section is dipped in ether, dried and mounted with mounting medium on microscope slide and a cover glass is affixed for microscopic studies.

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2

Development of Face and Oral Cavity

Prenatal development comprises 10 lunar months, 28 days each. It is divided into three successive phases—

1. Period of ovum—One week.
2. Embryonic period—Second week to eighth week.
 - a. Presomite
 - b. Somite
 - c. Postsomite period.
3. Period of fetus—Third month to tenth month.

Zygote—The mating of male and female gametes in the maternal uterine tube initiates the development of a large, totipotent cell (can give rise to cell of all type), having 100 μm diameter, known as zygote (Fig.2.1).

Morula—Zygote undergoes rapid mitotic division to form morula having sixteen pluripotent cells (can give rise to specialized form of tissue).

It has an inner cell mass which gives rise to embryo proper and is known as Embryoblast. The outer layer of cells are trophoblasts which help to provide nutrition to the embryo (Fig. 2.2).

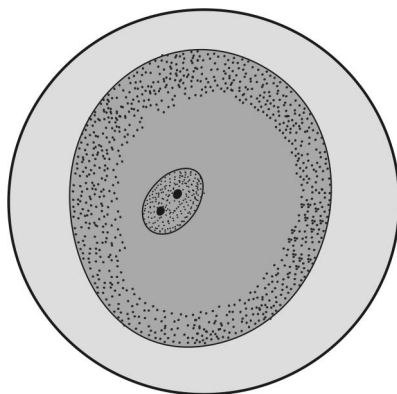


Fig. 2.1: Zygote

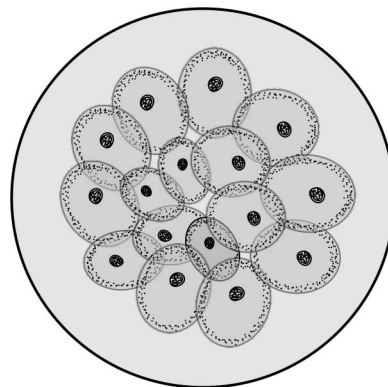


Fig. 2.2: Morula

Blastocyst—On fourth day, after conception, the fluid passes from uterine cavity into morula and partially separates the inner cell mass from the trophoblast. The morula now becomes a blastocyst (Fig. 2.3), and the cavity is known as blastocoele.

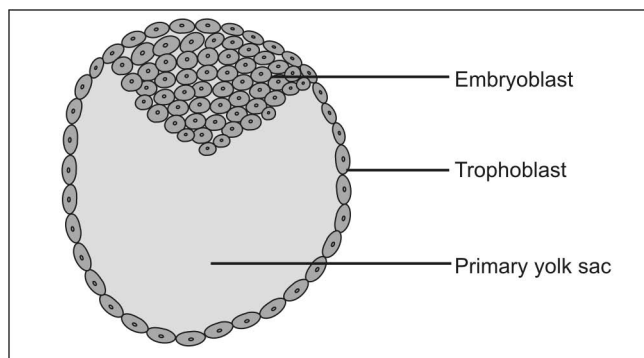


Fig. 2.3: Blastocyst

Placenta—On seventh day, the zygote passes through uterine tube and implants into uterine wall. The chorion develops from blastocyst by growth of villi into surrounding maternal uterine wall to tap blood supply. The surface directed villi eventually atrophy while basally directed villi hypertrophy and combine with uterine wall to form placenta (Fig. 2.4).

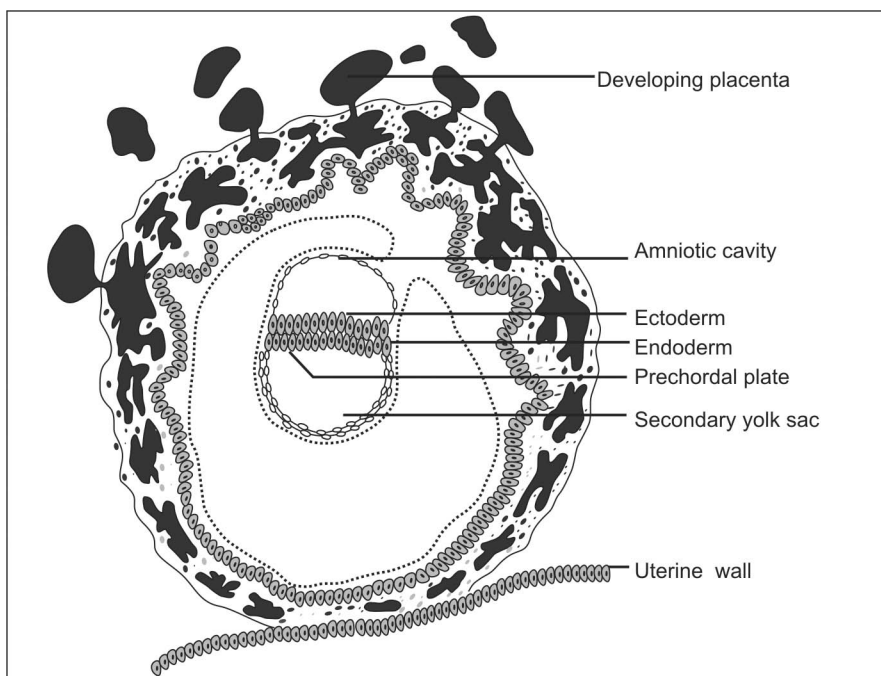


Fig. 2.4: Developing placenta and bilaminar germ disc

Bilaminar germ disc—Some cells of the inner cell mass differentiate into flattened cells which constitute endoderm, the first germ layer.

The remaining cells of the inner cell mass become columnar and form the ectoderm, the second germ layer.

At this stage, the embryo is in the form of a disc having two layers (Fig. 2.4).

Amniotic cavity—The space between the ectoderm (below) and the trophoblast (above) is amniotic cavity filled with amniotic fluid.

Yolk sac—The space between endoderm (above) and trophoblast (below) is yolk sac.

The fluid of amniotic cavity and yolk sac is meant for protection, nutritional exchange and waste elimination.

Prochordal plate—Around fourteenth day of development, at one circular area near the margin of the embryonic disc, the cubical cells of the endoderm become columnar.

This area is called prochordal plate (Fig. 2.5). It later forms the endodermal layer of oropharyngeal membrane. It determines the central axis of the embryo and also enables us to distinguish its future head and tail end.

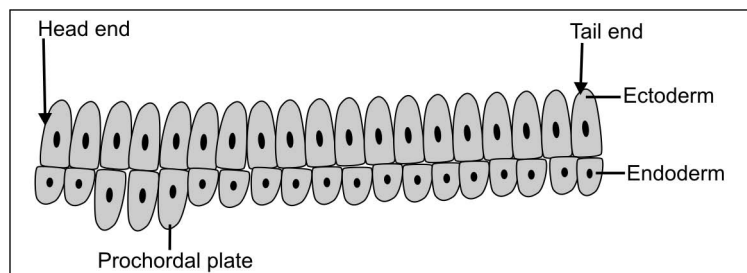


Fig. 2.5: Prochordal plate

Primitive streak—Around third week of development, some of the ectodermal cells lying along the central axis, near the tail end of the disc, begin to proliferate and form an elevation that bulges into amniotic cavity. This elevation is called the Primitive streak (Fig. 2.6).

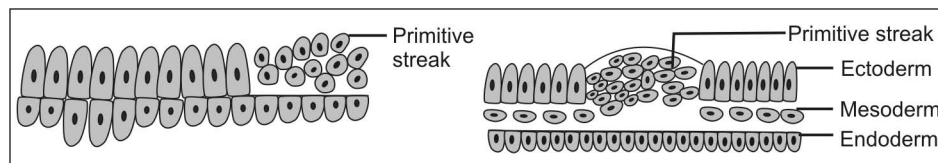


Fig. 2.6: Primitive streak

Mesoderm—The cells that proliferate in the region of primitive streak, pass side ways, pushing themselves between the ectoderm and the endoderm and form mesoderm, the third germ layer. The mesoderm migrate in all directions between the ectoderm and endoderm excepting near oropharyngeal membrane anteriorly and cloacal membrane posteriorly (Fig.2.7).

Notochord—The cells of the primitive streak proliferate and move cranially in the mid-line between the ectoderm and the endoderm, reaching upto the caudal margin of the prochordal

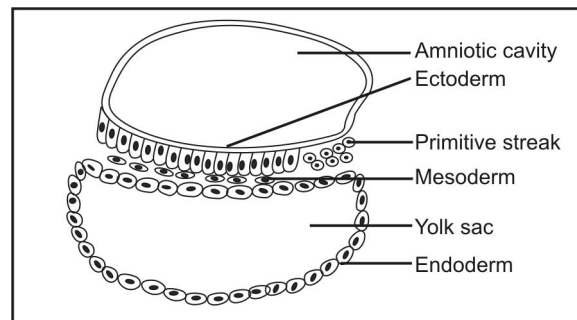
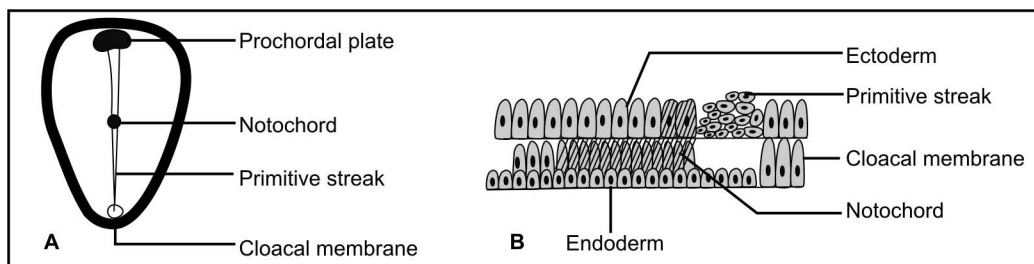
**Fig. 2.7:** Mesoderm

plate. The cells undergo differentiation and form a solid rod called notochord (Figs 2.8A and B) which lies in the mid-line, in the position to be later occupied by the vertebral column. However, the notochord does not give rise to vertebral column. The notochord terminates anteriorly at prochordal plate and marks the site of future pituitary gland. Most of the notochord disappears but parts of it persists in the region of each intervertebral disc as the nucleus pulposus.

**Figs 2.8A and B:** Notochord

Derivatives of Three Germ Layers

From Ectoderm

1. Skin and appendages
2. Central and peripheral nervous system
3. Oral mucous membrane.
4. Enamel.

From Mesoderm

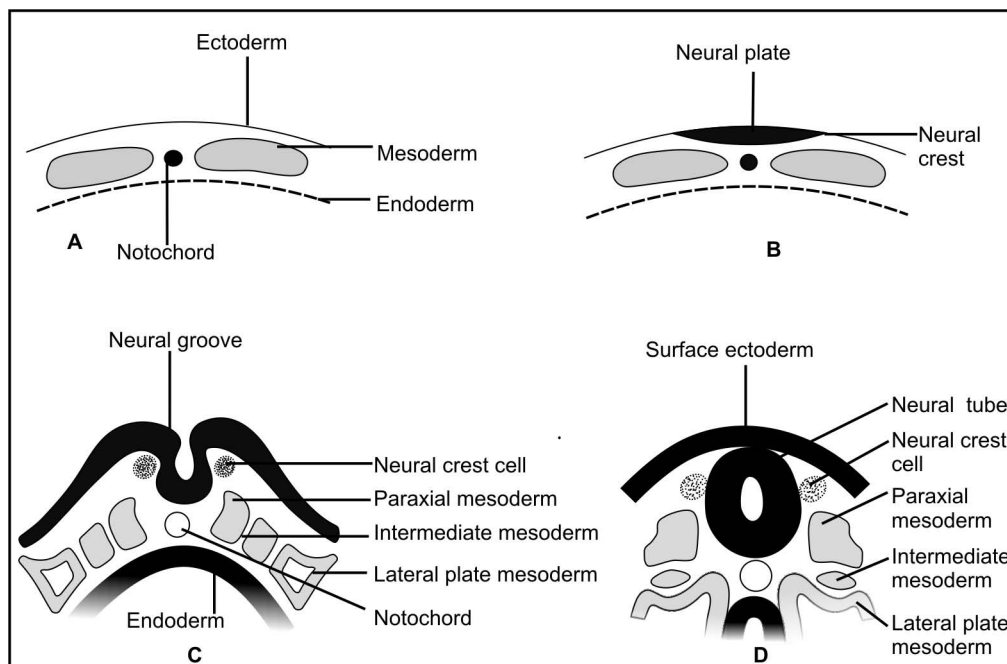
1. Cardiovascular system (Heart and blood vessel)
2. Locomotor system (Bones and muscles)
3. Connective tissue
4. Pulp, dentin, cementum, periodontal ligament and alveolar bone.

From Endoderm

1. Lining epithelium of alimentary canal between pharynx and anus
2. Secretory cells of liver and pancreas.
3. Lining epithelium of respiratory system.

Neural crest cells (Figs 2.9A to D): At the junction between the neural tube*and the surface (cutaneous) ectoderm on either side, groups of cells appear. They are known as neural crest cells. They are ectodermal in origin but have the properties of mesoderm. So they are known as ectomesenchyme. They are capable of migrating along the cleavage planes between mesoderm, ectoderm and endoderm. After reaching their destination, they undergo cytodifferentiation. Several important structures are derived from neural crest cells.They are—

1. The neurons of the sensory ganglia of the fifth, seventh, eighth, ninth and tenth cranial nerves.
2. The neurons of the sympathetic ganglia.
3. The Schwann cells
4. The specific cells of the adrenal medulla and chromaffin tissue.
5. Melanocytes
6. Calcitonin secreting cells
7. Cartilages of the branchial arches.



Figs 2.9: A. Embryonic disc, B. Formation of neural plate, C. Formation of neural groove and neural crest cells, D. The groove is converted to neural tube

8. Facial processes

9. All the tissues of the tooth (except enamel) and its supporting structures.

*[The ectoderm over notochordal process becomes thickened to form the neural plate which is depressed along the mid-line to form neural groove. The edges of the groove eventually fuse converting the neural groove into the neural tube (Figs 2.9A to D)]

[Clinical consideration—Proper migration of neural crest cells is essential for the development of the face and the teeth. In Treacher Collins' syndrome, full facial development does not occur due to failure of migration of neural crest cells to facial region. Depletion of neural crest cells prevents proper dental development].

Subdivisions of Mesoderm—(Figs 2.10 A and B)1. *Paraxial mesoderm*—It is the mesoderm, on either side of the notochord.

It becomes segmented to form a number of somites that lie on either side of the developing neural tube. (Figs 2.11A and B) 42-44 paired somites appear in cranio-caudal direction of which there are

4 occipital,

8 cervical,

12 thoracic,

5 lumbar,

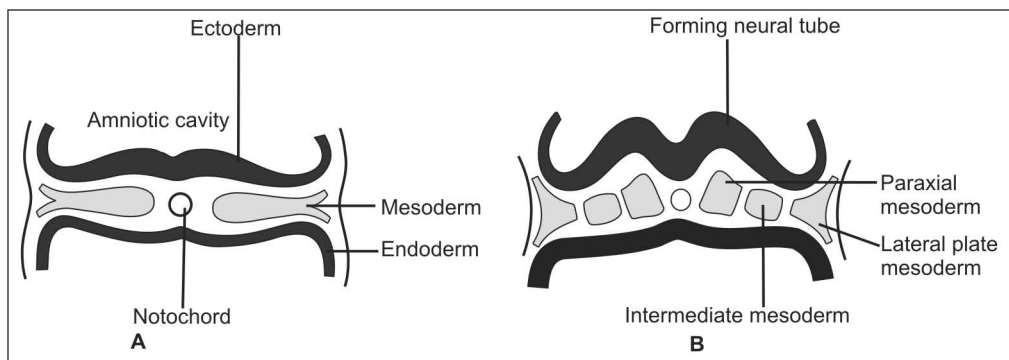
5 sacral,

8-10 coccygeal somites.

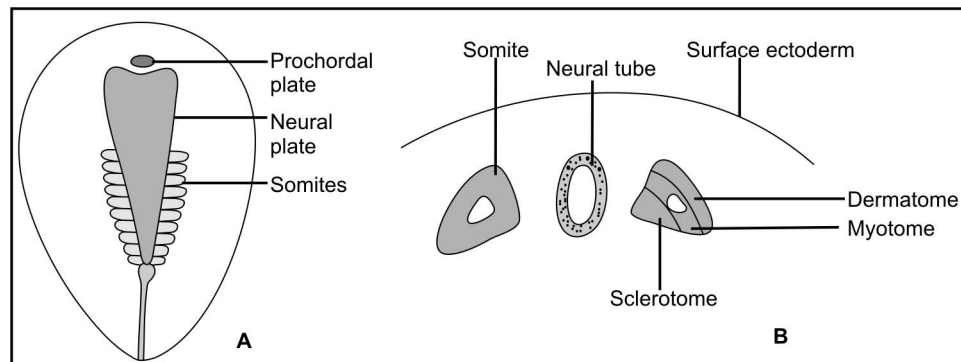
The somite is divisible into three parts—

- The ventromedial part is called the sclerotome. It gives rise to vertebral column and ribs.
- The lateral part is called the dermatome. The cells of this part give rise to dermis of the skin and subcutaneous tissue.
- The intermediate part is myotome. It gives rise to striated muscle. In the cervical, thoracic, lumbar and sacral regions one spinal nerve innervates each myotome.

In somite period, cardiovascular, alimentary system, nervous system, primordium of eye and internal ear develop.



Figs 2.10: A. Mesoderm between ectoderm and endoderm, **B.** Differentiation of mesoderm



Figs 2.11: A. Somites on either side of neural tube,
B. Subdivisions of somites

2. Lateral plate mesoderm—It is laterally placed and gives rise to
 - a. pleural, pericardial and peritoneal cavities,
 - b. connective tissue,
 - c. muscles of viscera,
 - d. blood,
 - e. lymph cells,
 - f. cardiovascular and lymphatic system,
 - g. spleen,
 - h. adrenal cortex
3. Intermediate mesoderm—It gives rise to urogenital system.

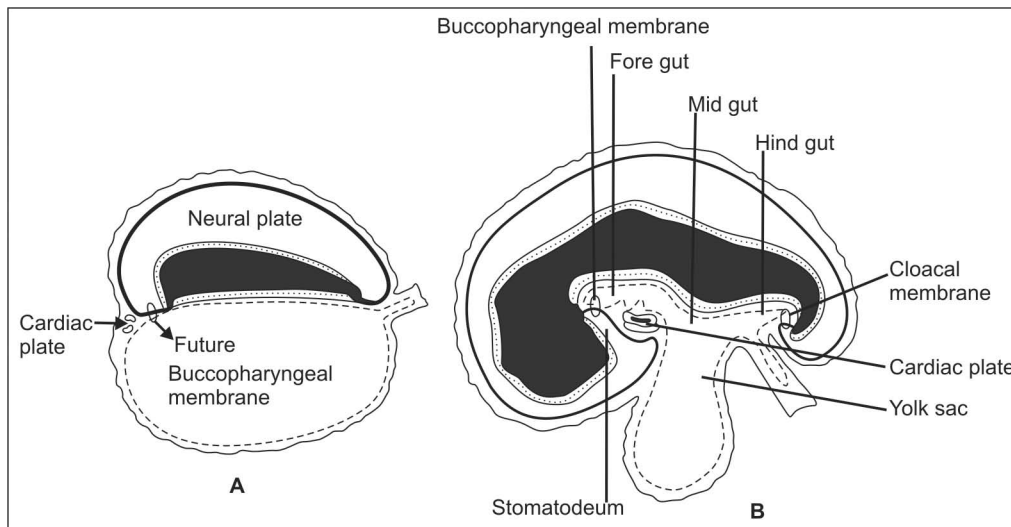
Folding of Embryo

At this stage, the embryonic disc undergoes lateral and cranio-caudal folds (Figs 2.12A and B).

With the formation of the head and tail folds, parts of the yolk sac become enclosed within embryo and a tube lined by endoderm is formed. This is primitive gut which is in direct communication with yolk sac. The part of the gut cranial to this communication is foregut. The part the gut caudal to this communication is hindgut and the intervening part is called midgut. The whole of the gut is sealed off anteriorly by oropharyngeal membrane and posteriorly by cloacal membrane. Later it is converted into a canal by breakdown of oropharyngeal and cloacal membrane.

Derivatives of Foregut Endoderm

1. Laryngotracheal diverticulum (Bronchi and lungs)
2. Hepatic and pancreatic diverticulum (Liver and pancreas)
3. Pharynx and pouches
4. Esophagus, stomach, first part of duodenum.



Figs 2.12: **A.** Craniocaudal folding begins, **B.** Completion of folding

Derivatives of Midgut Endoderm

1. Rest of duodenum
2. Entire small intestine
3. Ascending colon, transverse colon of large intestine.

Derivatives of Hindgut Endoderm

Descending colon and rest of alimentary canal.

Early Orofacial Development

Cranial end of embryo develops rapidly compared to caudal end.

Stomatodeum, the primitive oral cavity is a shallow depression, surrounded by neural plate cranially and cardiac plate caudally (Fig. 2.13). The buccopharyngeal membrane separates it from foregut. Stomatodeum forms the topographical center of developing face.

In the early somite period (21 to 31 day of embryo), five mesodermal elevations, augmented by neural crest cells and lined by ectoderm appear surrounding the stomatodeum. They are facial processes and constitute the initial features of face. The single, central most, cranially located process is frontonasal process and two bilaterally located processes are maxillary and mandibular processes (Fig. 2.14).

The different facial processes grow differentially and by obliterating the ectodermal grooves between them provide an even contour to the features of face (Fig. 2.15). The wide frontonasal process intervenes between the laterally placed developing eyes. It contributes to the forehead and nose. The olfactory part of nose develops from nasal (olfactory) placodes, which is formed from specialized epithelial thickening at the inferolateral corners of the frontonasal process.

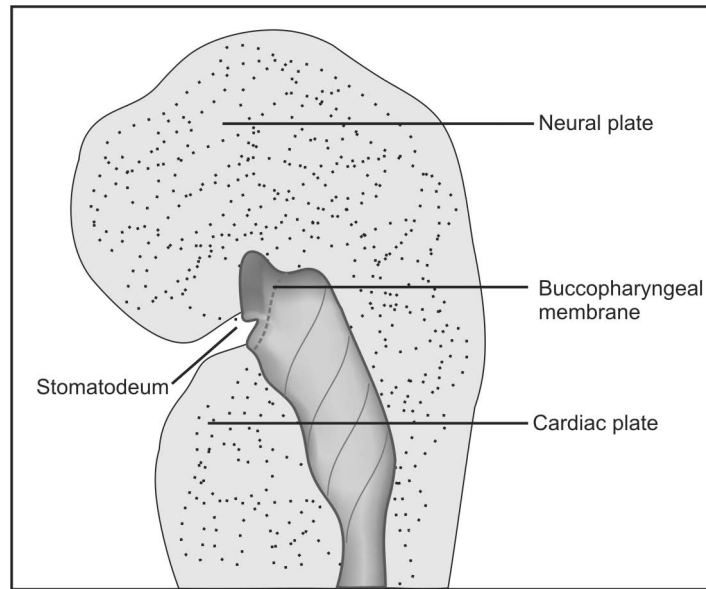


Fig. 2.13: Boundaries of stomatodeum between neural plate and cardiac plate

Globular process—During fifth week of intrauterine life (IU), horse-shoe shaped medial and lateral nasal processes develop surrounding each of the sinking nasal placodes and causes deepening of the nasal pits to form anterior nares. The two medial nasal processes approach

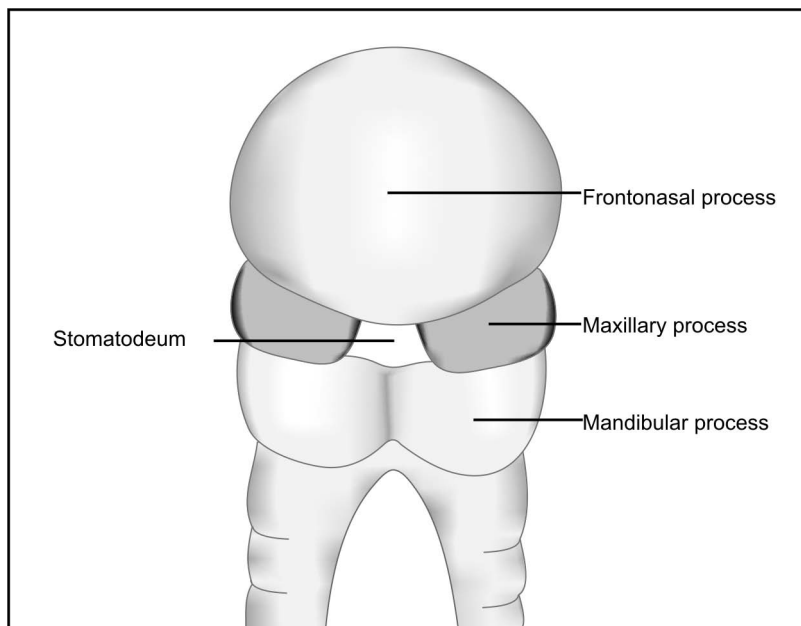


Fig. 2.14: Boundaries of stomatodeum between different facial processes

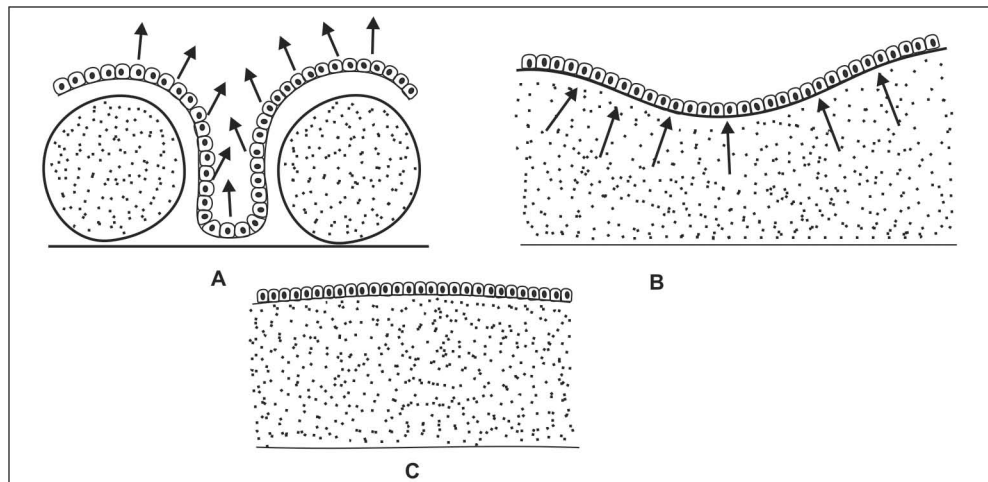


Fig. 2.15: Diagram illustrating obliteration of ectodermal grooves before fusion of facial processes

each other to form a single globular process (Fig. 2.16). It forms a) the tip of the nose, b) the columella, c) the philtrum, d) labial tuberculum of upper lip, e) labial frenum, and f) primary palate.

The elevation of the lateral nasal processes creates the alae of the nose.

The maxillary processes of each side form the lateral part of the lip, cheek and the maxillary processes merge with the frontonasal process by obliteration of intervening ectodermal groove, to provide continuity of upper lip and cheek region.

The two mandibular processes merge in the midline to provide continuity to the lower jaw and lip.

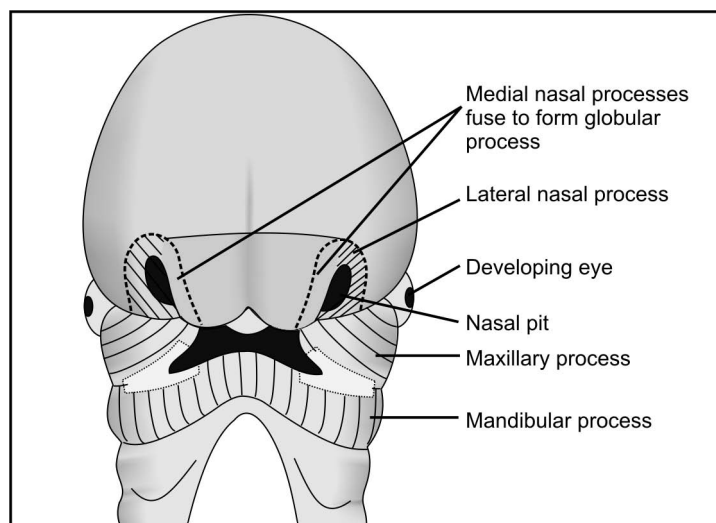


Fig. 2.16: Developing face

The maxillary process and the lateral nasal process are separated by deep furrow. The epithelium in the floor of the furrow form a solid core which eventually canalizes to form nasolacrimal duct. Once the duct is separated, the two processes merge by infilling of the mesenchyme.

Branchial Arches

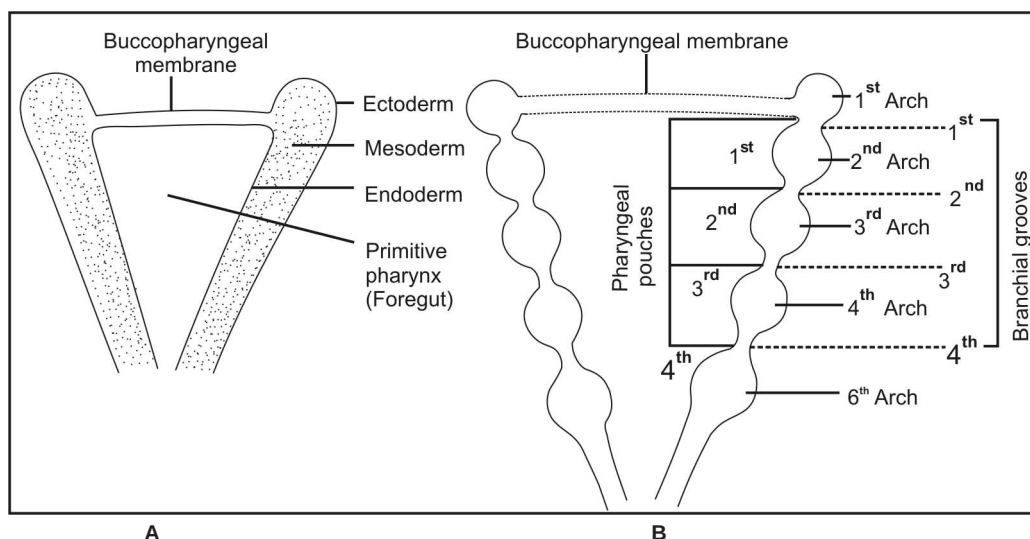
During the late somite period (Fourth week i.u.), a series of distinct, bilateral mesenchymal swellings, augmented by neural crest tissues, develop on the ventral aspect of the embryo, just caudal to the head fold, in the future mandibulocervical region. These sets of five or six elevations are known as branchial arches.

They are separated by four branchial grooves on the external aspect of the embryo.

Internally they are separated by the five out pocketings of the elongated pharynx of the foregut, known as pharyngeal pouch (Figs 2.17A and B).

The branchial arches decrease serially in size from the first to the sixth, each pair merging midventrally to form semicircular 'collars' around the pharynx. Only five pairs of arches are discernible, however, the fifth being transitory. In each pair of arches there are—

1. A central cartilage rod that forms the skeleton of the arch and are differentiated from neural crest tissue.
2. A vascular component—originate from lateral plate mesoderm.
3. A nervous element—consisting of sensory special visceral motor fibers of one or more cranial nerves supplying the mucosa and branchial muscle arising from that arch.
4. A muscular component—The branchiomer muscle component are of lateral plate mesoderm origin.



Figs 2.17A and B: Formation of branchial arches, branchial grooves and pharyngeal pouches

Table 2.1: Derivatives of branchial arches

<i>Branchial Arch</i>	<i>Skeleton</i>	<i>Muscle</i>	<i>Artery</i>	<i>Nerve</i>
1. Mandibular	Maxillary process, Palatal shelf, Mandible from Meckel's cartilage, incus, malleus, ant. lig. of malleus, spine of sphenoid bone, sphenomandibular ligament.	Muscles of mastication, (temporalis, masseter, medial and lateral pterygoid), Myelohyoid, ant. belly of digastric, tensor veli palatini, tensor tympani.	External carotid, maxillary artery.	Mandibular nerve
2. Hyoid	Stapes, styloid process, stylohyoid ligament, lesser horn and upper part of hyoid body.	Stapedius, stylohyoid, posterior belly of digastric, muscles of facial expression, platysma, occipito-frontalis, auricular muscle.	Stapedial and facial artery	Facial nerve
3. Third	Greater horn and lower part of hyoid body	Stylopharyngeus	Internal carotid and common carotid	Glossopharyngeal nerve
4. Fourth	Thyroid cartilage	Cricothyroid, constrictors of the pharynx, levator veli palatini, uvular muscles of the soft palate, palatoglossus muscle.	Arch of aorta (left) proximal part of right subclavian artery.	Superior laryng. branch of vagus nerve
5. Sixth	Cricoid and arytenoids cartilage	Intrinsic muscles of larynx	Proximal part of both pulmonary arteries and ductus arteriosus (left)	Recurrent laryngeal nerve of vagus

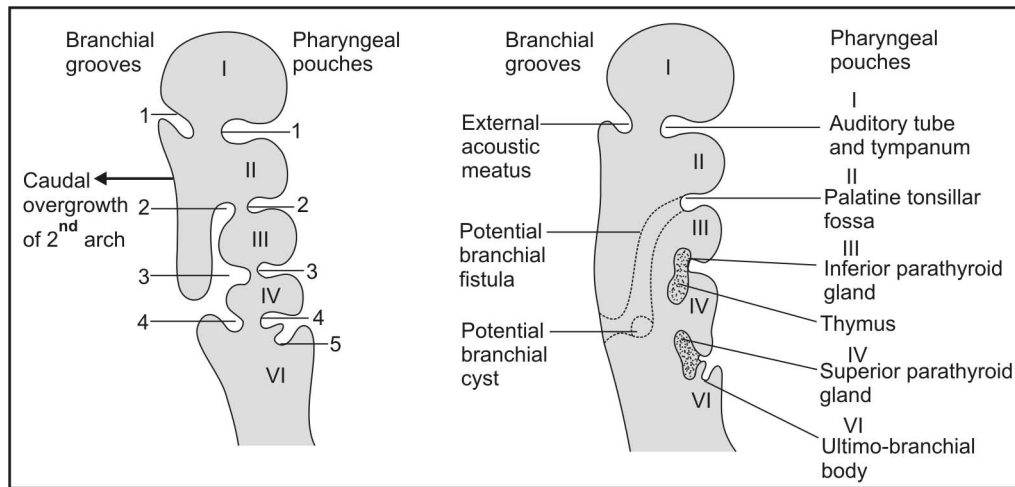
The Branchial Grooves and Pharyngeal Pouches

After the formation of branchial arches, between primitive stomatodeum and developing heart, they are marked on outside by a series of grooves, lined by surface ectoderm and are known as branchial grooves. On the inner aspect of pharyngeal wall are corresponding small depression lined by foregut endoderm called pharyngeal pouches that separate each of the branchial arches internally (Fig.2.18A).

Fate of Branchial Groove

The first branchial groove persists and deepens to form the external acoustic meatus. The ecto-meso-endodermal membrane in the depth of the groove, separating it from the first pharyngeal pouch, persists as the tympanic membrane.

The second, third and fourth branchial grooves become obliterated by caudal overgrowth of the second branchial arch, which provides a smooth contour to the neck. Failure to obliterate completely these branchial grooves result in a branchial fistula leading from the pharynx to the outside or a branchial sinus or cyst, forming a closed sac (Fig.2.18B).



Figs 2.18A and B: Fate of branchial groove and pharyngeal pouches

Fate of Pharyngeal Pouches

The five pairs of pharyngeal pouches on the sides of the pharyngeal foregut form dorsal and ventral pockets, of which endodermal epithelium differentiates into a variety of structures. Elongation of the third, fourth and fifth pharyngeal pouches during the 6th and 7th weeks in, increasingly dissociates the pouches from the pharynx and allows their derivatives to form in the lower anterior neck region.

First Pharyngeal Pouch

The ventral portion of this pouch is obliterated by the developing tongue. The dorsal diverticulum deepens laterally as the tubo-tympanic recess to form the auditory tube, widening at its end into the tympanum or middle ear cavity, separated from the first branchial groove by the tympanic membrane. The tympanum becomes occupied by the dorsal ends of the cartilages of the first and second branchial arches that later develop into ear ossicles. The tympanum maintains contact with the pharynx via the auditory tube throughout life.

Second Pharyngeal Pouch

The ventral portion of this pouch is obliterated by the developing tongue. The dorsal portion forms palatine tonsil and tonsillar fossa.

Third Pharyngeal Pouch

The ventral diverticulum endoderm proliferates and migrates from each side to form single median thymus gland. The dorsal diverticulum endoderm differentiates and migrates caudally to form the inferior parathyroid gland.

Fourth Pharyngeal Pouch

The fate of endoderm of the ventral diverticulum is uncertain. The lining membrane may possibly contribute to thymus or thyroid tissue.

The dorsal diverticulum endoderm differentiates into the superior parathyroid gland, which after losing contact with the pharynx, migrates caudally with thyroid gland.

Fifth Pharyngeal Pouch

The fifth pouch appears as a diverticulum of the fourth pouch, the endoderm of which forms the ultimobranchial body. The calcitonin secreting cells of the ultimobranchial body are derived from neural crest tissue and are eventually incorporated into thyroid gland.

Formation of the Tongue

The tongue begins to develop at about 4th week of intra-uterine life in the ventral wall of the primitive oropharynx in relation to first four branchial arches.

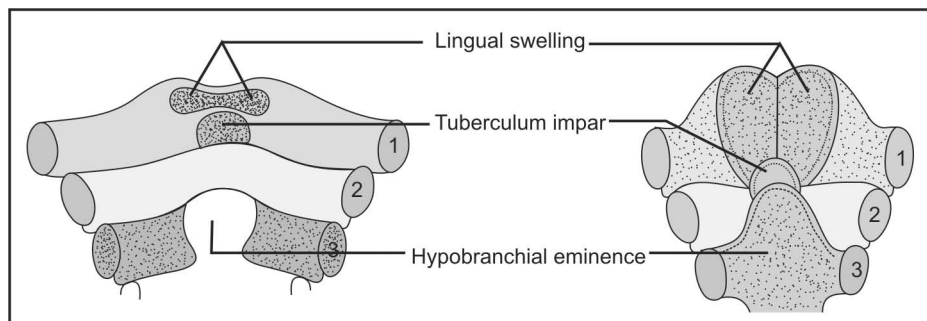
Paired lateral proliferation of mesenchyme appear on the internal aspect of first branchial arch to form lingual swellings (Fig. 2.19). Between and behind the lingual swellings there appears a median eminence, the tuberculum impar; its caudal border is marked by a blind pit, the foramen caecum, from which the epithelium proliferates to form a downgrowth, thyroglossal duct, from which the thyroid gland develops.

Another midline swelling appears in relation to the medial ends of the second, third and fourth arches. This swelling is called the hypobranchial eminence (Fig. 2.20) which soon shows a subdivision into a cranial part related to the second and third arches (called the copula) and a caudal part related to the 4th arch (Fig. 2.21A). The caudal part forms the epiglottis.

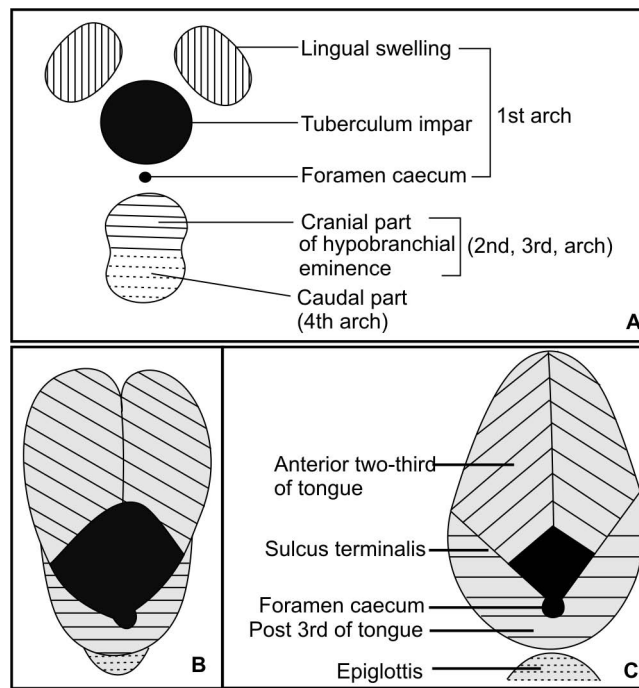
The anterior two-third of the tongue is formed by fusion of—

- a. The tuberculum impar and
- b. The two lingual swellings

The anterior two-third of the tongue is thus derived from the mandibular arch (Figs 2.21 B and C). According to some, the tuberculum impar does not make a significant contribution to the tongue.



Figs 2.19 and 2.20: Development of tongue

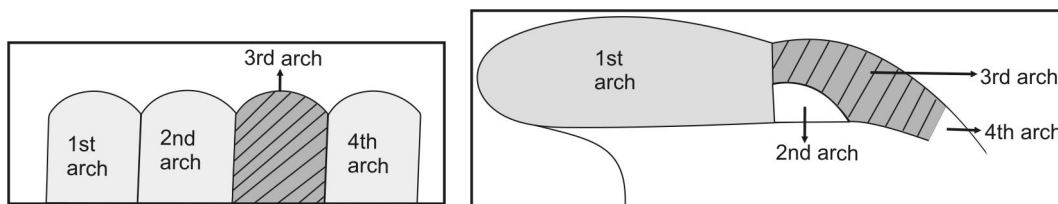


Figs 2.21A to C: Origin of different parts of tongue

The posterior one-third of the tongue is formed from the cranial part of the hypobranchial eminence (copula) (Fig. 2.22). In this situation, the second arch mesoderm gets buried below the surface. The third arch mesoderm grows over it to fuse with the mesoderm of the first arch (Fig. 2.23). The posterior one-third of the tongue is thus formed by third arch mesoderm.

The posterior most part of the tongue is derived from the fourth arch (Fig. 2.24). AV-shaped sulcus terminalis, whose apex is the foramen caecum, demarcates the junction between anterior two-third and posterior one-third of tongue.

According to the embryological origin, the anterior two-third of the tongue is supplied by the lingual branch of the mandibular nerve, which is the post trematic nerve of the first arch and by the chorda tympani which is pre-trematic nerve of this arch. The posterior one-third of the tongue is supplied by the glossopharyngeal nerve, which is the nerve of the third arch. The



Figs 2.22 and 2.23: Second arch is buried by the overgrowth of the third arch

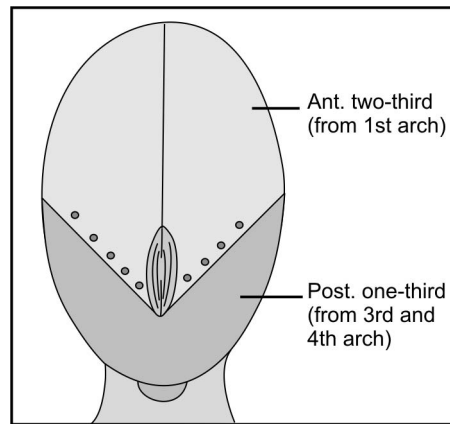


Fig. 2.24: Final disposition of the tongue and the relative contributions from branchial arches

most posterior part of the tongue is supplied by the superior laryngeal nerve, which is the nerve of the fourth arch. The musculature of the tongue is derived from the occipital myotomes and are supplied by the hypoglossal nerve, which is the nerve of these myotomes.

The epithelium of the tongue is at first made up of a single layer of cells. Later it becomes stratified and papillae become evident. The line of the sulcus terminalis is marked by 8 to 12 circumvallate papillae that develop at 2-5 months of i.u. The mucosa of the dorsal surface of the body of the tongue develops filiform and fungiform papillae at 11 weeks i.u. At birth, the root mucosa becomes pitted by deep crypts that develop into lingual tonsil, the completion of which is marked by lymphocytic infiltration. Taste buds arise by inductive interaction between epithelial cells and nerve cells from the chorda tympani, glossopharyngeal and vagus nerves.

Development of Palate

The palate is developed from three components:

1. The primitive palate, formed from globular process, and
2. The two palatal process from maxillary process.

Initially there is a common oronasal cavity bounded anteriorly by the primary palate and occupied mainly by the developing tongue. Around 7-8 weeks of development, the maxillary processes which form the lateral wall of primitive oronasal cavity develop processes on each side at the lateral portion of oral roof. They grow downward vertically on either side of tongue. The processes are called palatine processes (palatine shelves). After the seventh week of development, (Fig. 2.25) the tongue is withdrawn from between the shelves, which now elevate and fuse with each other above the tongue and with the primary palate. (Fig. 2.26). The fusion begins anteriorly and proceeds backward.

The closure of the secondary palate involves:

- a. An intrinsic force in the palatal shelves,
- b. The high concentration of glycosaminoglycans, which attract water and make shelves turgid,

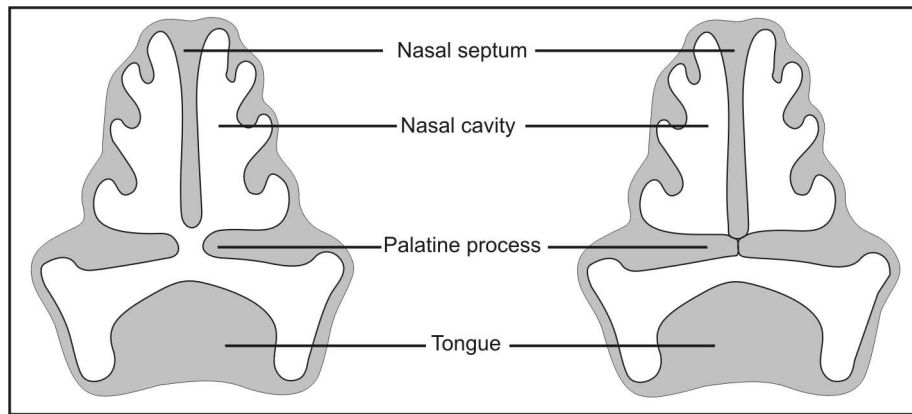


Fig. 2.25: Fusion of palatine processes

- c. Presence of contractile fibroblasts in the palatine shelves,
- d. Displacement of the tongue from between the palatine shelves by the growth pattern of the head.

24 to 36 hours before fusion of palatine processes, there is cessation of DNA synthesis within epithelium. Surface epithelial cells are sloughed off as they undergo physiologic cell death (Apoptotic cell death).

The basal cells have a carbohydrate-rich surface coat that permits adhesion between processes. The single layer of basal cells ultimately breaks into discrete islands of epithelial cells and there is ectomesenchymal continuity between the fused processes.

At a later stage, the mesoderm in the palate undergoes intramembranous ossification to form hard palate. However, ossification does not extend into the most posterior portion, which remains as the soft palate.

Development of the Jaws

At about sixth week of intra-uterine life, the first indication of bone formation for the jaws is seen. Both the mandible and maxilla form from the tissues of the first branchial arch, the mandible forming within the mandibular process and maxilla within the maxillary process.

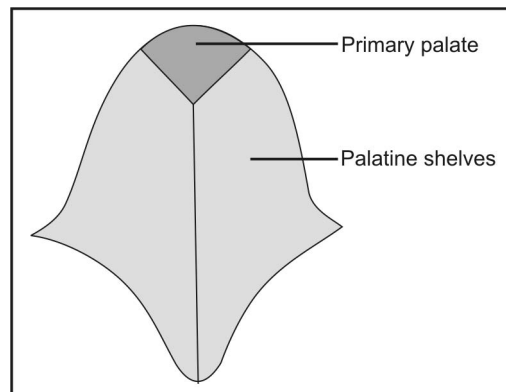


Fig. 2.26: Fusion of palatine shelves and primary palate

Development of the Mandible

The mandible is partly intramembranous and partly intracartilagenous in origin. Greater part of body, ramus, condyloid and coronoid processes are intramembranous in origin. Only the tip of condyloid and the coronoid processes and symphyseal region are of endochondral origin.

Meckel's cartilage, the cartilage of the first arch has a close positional relationship to the developing mandible but makes no contribution to it. It only acts as a scaffold and a guideline. The cartilage attains its full form by six weeks and grows forward and downward towards midline. It is surrounded by a thick fibrocellular tissue. The mandibular nerve and mandibular artery are in close contact with Meckel's cartilage. The mandibular nerve divides into the lingual and inferior dental branches near about the junction of dorsal and middle third of the cartilage. The lingual nerve runs medially and the inferior dental nerve runs laterally and divides into mental and inferior branches. The mental branch runs away from the cartilage and the incisive runs along with the cartilage (Fig. 2.27).

At seventh week, first intramembranous ossification is observed in the dense fibrocellular tissue outside and lateral to Meckel's cartilage, at the fork formed by the incisive nerve and mental nerve (in the region of future mental foramen). From this center of ossification, bone formation spreads rapidly anteriorly to the midline and posteriorly towards the point where the mandibular nerve divides into its lingual and inferior alveolar branches. This spread of new bone consists of lateral and medial plates that unite beneath the incisive nerve. This trough of bone extends to the midline, where it comes into close approximation with a similar trough formed in the adjoining mandibular process. The two separate centers of ossification remain separated at the mandibular symphysis until shortly after birth. This trough is soon converted into a canal as bone forms over the nerve joining the lateral and medial plates. Similarly, a backward extension of ossification along the lateral aspect of Meckel's cartilage, forms a trough, later converted into a canal, that contains the inferior alveolar nerve.

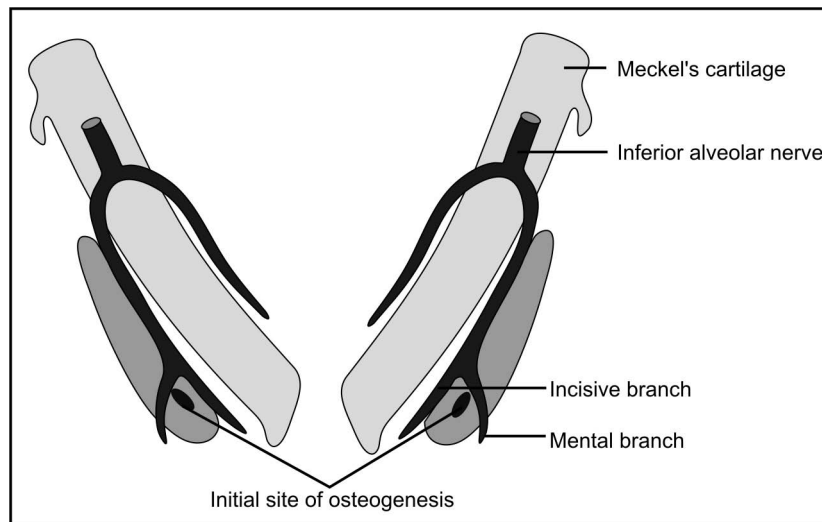


Fig. 2.27: Site of initial osteogenesis related to mandible formation

From the bony canal which extends from division of the mandibular nerve to the midline, medial and lateral alveolar plates of bone develop in relation to the forming tooth germs, which occupy a secondary trough of bone. This trough of bone is partitioned and thus each developing tooth occupy individual compartment which finally is totally enclosed by growth of bone over the tooth germ. In this way the body of the mandible is essentially formed.

The ramus of the mandible develops by rapid spread of ossification posteriorly into the mesenchyme of the first arch, turning away from Meckel's cartilage (Fig. 2.28). This point of divergence is marked by the lingula in the adult mandible, the point at which the inferior alveolar nerve enters the body of the mandible.

By the tenth week, the rudimentary mandible is formed entirely by membranous ossification. The further growth of the mandible until birth is strongly influenced by the appearance of three secondary cartilages and the development of muscular attachment. The secondary cartilages are condylar cartilage, coronoid cartilage and symphyseal cartilage.

[Secondary cartilages have larger cells and less intercellular matrix compared to primary cartilage].

The condylar cartilage appears during the twelfth week of development and rapidly forms a cone or carrot shaped mass that occupies most of the developing ramus. The mass of cartilage is quickly converted to bone by endochondral ossification, so that at 20 weeks only a thin layer of cartilage remains at condylar head. This remnant of cartilage persists until the end of the second decade of life. The coronoid cartilage appears at about 4 months of development and disappears long before birth.

The symphyseal cartilages, two in number, appear in the connective tissue between the two ends of Meckel's cartilage, but are entirely independent of it. They are obliterated within the first year after birth.

Small islands of cartilage may also appear as variable and transient structures in the developing alveolar processes.

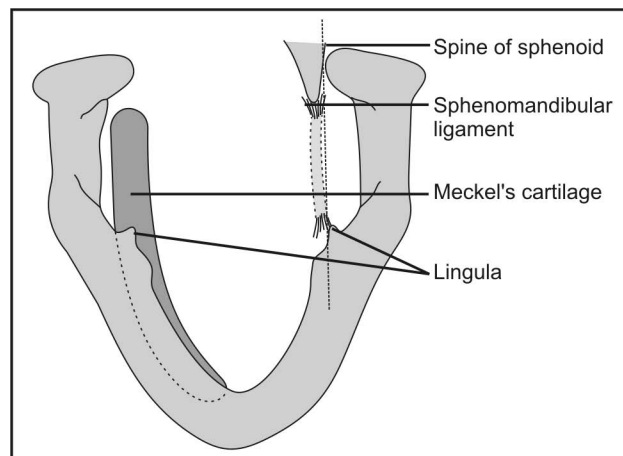


Fig. 2.28: Spread of mandibular ossification away from Meckel's cartilage at the lingula

Thus the mandible is a membrane bone, developed in relation to the nerve of the first arch and almost entirely independent of Meckel's cartilage. It has neural, muscular, alveolar elements (Fig. 2.29) and its growth is assisted by development of secondary cartilage.

Meckel's cartilage—It is the cartilage of first arch, attains its full form by six weeks and then grows forward and downward towards midline. Two solid hyaline cartilaginous rod of each side do not meet at midline but are separated by a thin band of mesenchyme. Mandibular nerve and artery have close relationship to Meckel's cartilage.

Function

1. It has a close positional relationship to the developing mandible but makes no contribution to it. It acts as scaffold and a guideline for formation of mandible.
2. The dorsal end of cartilage gives rise to two middle ear bones, incus, malleus by intracartilaginous ossification.
3. Formation of sphenomandibular ligament.

Fate—From the sphenoid bone to the division of mandibular nerve into its alveolar and lingual branches, the cartilage is totally lost, but its fibrocellular capsule persists as sphenomandibular ligament. From the lingula forward to the division of the alveolar nerve into its incisor and mental branches, Meckel's cartilage is totally resorbed. Near the midline one or two nodules of cartilage are seen in late fetal life and at birth. These cartilages may ossify to form small contribution to mandible at symphysis.

Development of Maxilla

The maxilla is formed by maxilla proper and premaxilla. The maxilla proper is developed as an extension of mandibular arch. It forms by intramembranous ossification. Ossification starts at about 6 weeks of intra-uterine life. The ossification center appears near the part which forms enamel organ of the canine tooth germ and also lateral and below the fork formed by infraorbital nerve and anterior superior alveolar nerve. From this center, bone formation spreads posteriorly below the orbit towards the developing zygoma and forwards towards premaxilla. It unites with premaxilla at an early stage. Ossification also spreads superiorly to form the frontal process. As a result of this pattern of bone deposition, a bony trough forms for the infraorbital nerve.

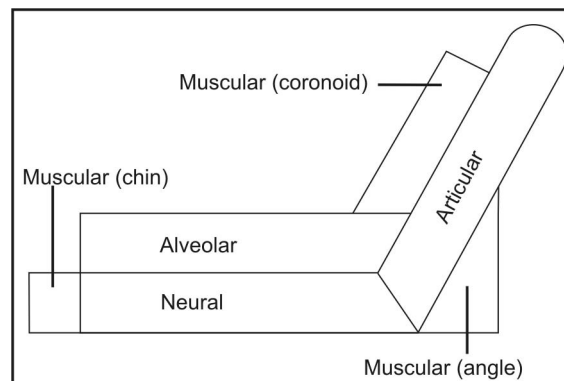


Fig. 2.29: Differing developmental blocks for the mandible

From this trough a downward extension of bone forms lateral to alveolar plate for the maxillary tooth germ. Ossification also spreads into palatine process to form hard palate. The medial alveolar plate develops from the junction of the palatal process and the main body of the forming maxilla. This plate, together with its lateral counterpart, forms a trough of bone around the maxillary tooth germs, which eventually become enclosed in bony crypts.

A secondary cartilage also contributes to the development of maxilla. A zygomatic cartilage appears in the developing zygomatic process and adds to the development of maxilla.

The maxillary sinus appears at 16th week fetal life as a projection from nasal cavity. It comes in contact with maxilla after cartilage of nasal capsule atrophies. It increases gradually and separates the orbital surface from dental surface. The final height is reached after eruption of all permanent teeth.

Development of the Temporomandibular Joint

The temporomandibular joint (TMJ) is an articulation between two bones initially formed from membranous centers of ossification. At seventh week, the Meckel's cartilage extends from chin to base of the skull. This joint is replaced by the temporomandibular joint near the end of fetal life.

Articular disc seems to be a muscle derivative of first branchial arch. There is first a mesenchymal condensation on the upper end of mandibular ramus. Anteriorly, this mesenchyme extends from superior border of lateral pterygoid muscle to medial side of masseter muscle. The lateral pterygoid muscle contributes to the formation of medial part of articular disc. Mesenchymal condensation form the fibrous covering on the joint surfaces. At twelfth week mandibular condylar cartilage appears. At thirteenth week the condyle with articular disc come in contact with temporal bone and inferior joint cavities develop, followed by superior cavity. The disc is first vascular. Later on as the disc is compressed, central and anterior part becomes avascular. The disc loses its connection with malleus and attaches itself to the squamo-tympanic fissure. The synovial lining of the joint cavities appear later.

Development of the Skull

The skull can be divided into three components—(Fig. 2.30)

1. The cranial vault.
2. The cranial base.
3. The face.

Biologically, the skull consists basically of two bones, mandible and cranium.

For the purpose of understanding the growth of head, face and jaw may be described under following headings:

1. Growth of cranium.
 - a. growth of cranial vault.
 - b. growth of cranial base.
2. Growth of face.
 - a. growth of upper face.
 - b. growth of lower face.
3. Growth of air sinuses.

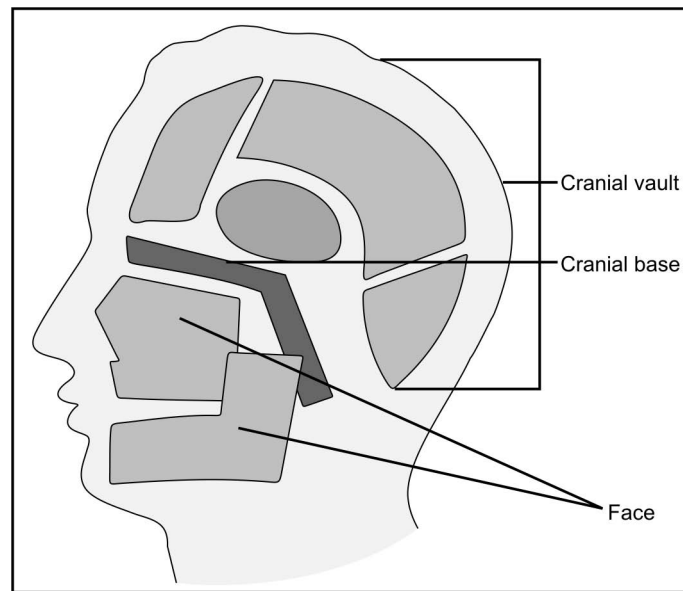


Fig. 2.30: Sub divisions of skull

Growth of Cranial Vault

The cranial vault is made up of the following membrane bones: the frontal, parietals, squamous part of the temporals and part of occipital and sphenoid. These bones grow as different parts of a single bone and then fuse to form the cranial vault.

The cranium grows because the brain grows (Fig.2.31). The brain grows quicker than the face. The brain triples in volume in first two years of life and then slows down considerably. By five years, 90% of brain growth has taken place. The growth of cranial vault is accomplished primarily:

1. by proliferation and ossification of connective tissue at sutural lines,

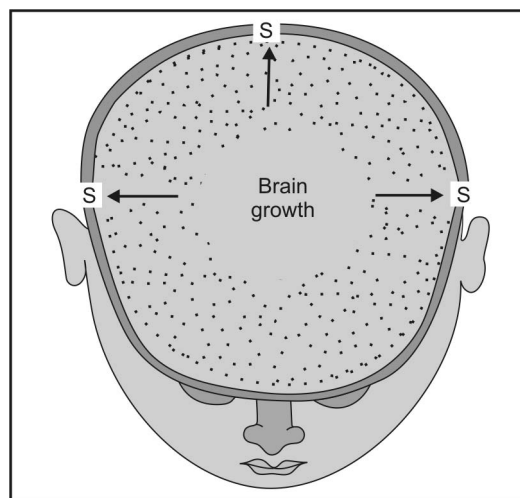


Fig. 2.31: Growth of the brain stimulates the sutural growth of the skullcap

2. by appositional growth of individual bones,
3. by selective resorption in early postnatal life at the inner surface in the areas close to sutural borders,
4. apposition of bone on the inner surface in the central areas.

This selective resorption helps in flattening of the skull as it grows. Apposition is seen on both inner and outer plates of bones. This thickening of bone is not uniform throughout because the outer plate of bone of the cranial superstructure is under the influence of masticatory and other mechanical forces. Thickening is specially seen on supraorbital region, mastoid region and tympanic region.

Increase in length of the cranial vault is due to active growth at the fronto-parietal suture and parieto-occipital suture.

Increase in width is due to growth at interparietal, parieto-sphenoidal, and parieto-temporal sutures.

The height of the brain case grows due to the growth at parieto-occipital, parieto-sphenoidal and parieto-temporal sutures.

Growth of Cranial Base

In contrast to the cranial vault, the base grows primarily by growth of cartilage. The areas participating in the growth are sphenio-ethmoidal, sphenio-occipital and intra-occipital synchondrosis. The growth activity at inter-sphenoidal synchondrosis disappears after birth. The activity of inter-occipital synchondrosis is up to 5 years, of sphenio-ethmoidal synchondrosis is from 5 to 25 years and of sphenio-occipital synchondrosis is up to 20 years.

Growth of Face

Facial bones grow at a faster rate than bones of the vault after first year and continues to grow for a long time.

The Upper Face

The upper face consists of a naso-maxillary complex. It is attached to the base of the skull. The growth of the cranial base is due to endochondral ossification and the growth of the maxillary complex is mostly a sutural growth like that in the cranial vault.

The maxilla is joined to the cranium via four pairs of sutures (Fig. 2.32).

1. Fronto-maxillary suture
2. Zygomatico-maxillary suture
3. Zygomatico-temporal suture
4. Pterygo-palatine suture.

The downward and forward growth of maxilla is due to

1. Growth of connective tissue in the suture,
2. Endochondral growth of cranial base and nasal septal cartilage.

Increase in height of maxillary complex is due to continued apposition of alveolar bone during eruption of teeth.

Growth in width is due to growth along median palatal suture. Other sutures that contribute to the width are in relation to ethmoid, zygomatic, lacrimal and nasal bones.

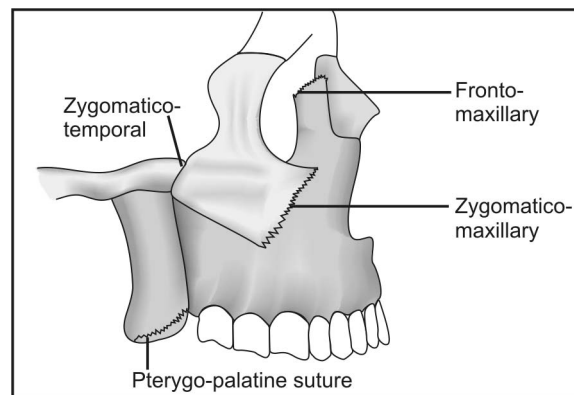


Fig. 2.32: Growth mechanism at upper face

The lower face—The lower face consists of mandible which is formed at fetal period. At birth, the condyles are short, right and left halves are separated in the midline by a thin line of fibrocartilage. By the end of first year, the symphyseal cartilage is replaced by bone.

There is proliferation of the condylar cartilage and its replacement by bone in the deepest layer. Condylar growth pushes mandible downward and forward.

There is apposition along the posterior border of ramus with resorption along the anterior border. This increases the length of the body of mandible.

There is apposition on the alveolar border and consequently there is increase in height.

The width increases by apposition on outer surface and posterior border.

The additive growth on the posterior border increases the distance between the terminal points of angles of the mandible.

Additive growth at the coronoid process, sigmoid notch and condyle also increases superior inter-ramus dimension.

Along with the developing dentition, alveolar border increases the height of the body of mandible. Growth of alveolus also increases the width of the body of the mandible.

Growth of Air Sinuses

Air sinuses develop as: (1) evaginations of the nasal cavity, or (2) expansion of the cavity of middle ear into the adjacent bones.

Air sinuses reduce the weight of the bones without reducing the functional efficiency considerably. The growth of the sinuses is secondary to the growth of bone.

The frontal sinus starts forming in the second year of life. The two frontal sinuses grow at a different rate and are separated by a thin septum. The air sinuses increase in volume at old age.

The sphenoid sinus develops in the second year of life as the body of the sphenoid bone hollows out. It gradually increases in size.

The maxillary sinuses develop as an evagination from middle nasal meatus just before birth. Its growth is dependant upon eruption of teeth. It expands throughout life.

The mastoid air sinuses develop along mastoid process. In the second year of life the formation of mastoid sinus commences.

Development of Salivary Gland

There are three pairs of major and innumerable minor salivary glands in the oral cavity. They arise as buds from oral epithelium and grows into the underlying connective tissue. The parotid and submandibular buds appear during six week and that of sublingual gland appear during seventh week. Minor salivary glands appear later. The epithelial buds ramify as solid cords with small terminal enlargements, the acini. Later, the solid cords are canalized to give rise to duct system. The cells of acini are specialized for secretion. The majority of glands are ectodermal in origin, though some glands about the base of the tongue are endodermal. The connective tissue component and nervous system play important role in the growth of salivary gland.

Clinical Consideration

Nonunion of the part or whole of one process with another frequently result in malformation of face, lip, palate and jaws. Nonunion of processes may be due to deficiency of mesenchyme in the facial region, failure of facial mesenchyme to proliferate, failure of the neural crest cells to migrate.

Cleft lip—may be unilateral or bilateral. It is the result of nonunion of globular process and maxillary processes.

Cleft palate—may be unilateral, bilateral, incomplete or complete involving both soft and hard palate.

Cleft palate is due to non-union of two palatine processes. Anteriorly nonunion of premaxilla (globular process) and maxilla (palatine process) result in a complete bilateral Y-shaped cleft palate.

Oblique facial cleft—is due to non-union of maxillary and lateral nasal process.

Lateral facial cleft and macrostomia—are due to failure of maxillary and mandibular processes to fuse.

Microstomia—is overclosure of mouth opening due to excessive merging of the maxillary and mandibular processes.

Labial pits—Small pits may persist on either side of midline lower lip. They are caused by failure of embryonic labial pits to disappear.

Bifid tongue—is due to lack of fusion between two lateral lingual prominences.

Lingual thyroid—Thyroid tissue may be present in the base of tongue. Part of thyroglossal duct may persist and form cysts at the base of tongue.

Branchial cleft cyst or fistulas- may arise from the rests of epithelium in the visceral arch area and are laterally disposed on the neck.

Thyroglossal duct cyst—may occur at any place along the course of the duct, usually at or near the midline.

Fissural Cyst

Median palatine cyst—arises from epithelial inclusions at the line of fusion of palatal processes.

In relation to other facial processes, fusion occurs by obliteration of ectodermal grooves and not by apoptotic cell death of intervening epithelium. So the cysts in other line of fusion are not fissural cyst.

Cleft mandible—is a rare condition found due to non-union of two mandibular processes.

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Development of the Tooth

The primitive oral cavity or stomodeum, is lined by epithelium (two or three cell layer thick). Beneath the epithelium, there is an embryonic connective tissue, enriched with neural crest cells and is termed ectomesenchyme.

In hematoxylin and eosin stained section, the epithelial cells appear vacuolated (once filled with glycogen which is washed out of cells during tissue preparation).

The ectomesenchyme consists of a few spindle-shaped cells separated by gelatinous ground substance.

At about 4th week of development buccopharyngeal membrane ruptures and primitive oral cavity establishes a connection with foregut. The neural crest cells are thought to induce the overlying ectoderm to start tooth development.

Primary Epithelial Band

At about 6th week of development, certain areas of basal cells of oral ectoderm proliferate at more rapid rate than do the cells of the adjacent areas. There is condensation of mesenchymal tissue and of capillary network beneath the proliferating epithelium. The thickened oral epithelium invaginates into mesenchyme to form primary epithelial band (Fig. 3.1).

By the 7th week, the primary epithelial band divides into two processes by invagination of underlying ectomesenchyme. The processes are buccally located vestibular lamina and lingually located dental lamina (Figs 3.2A and B).

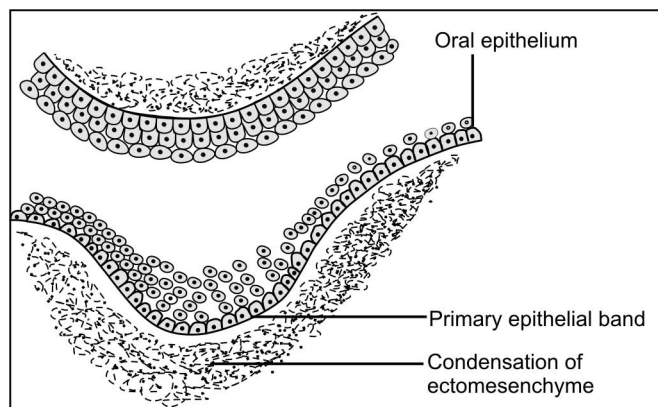


Fig. 3.1: Primary epithelial band

The vestibular lamina contributes to the development of the vestibule, delineating the lips and cheeks from the tooth-bearing region. The dental lamina contributes to the development of the teeth.

The cells of the vestibular lamina proliferate. Subsequently, there is degeneration of the central epithelial cells, which results in the formation of a sulcus, the vestibule between the alveolar portion of the jaws and lips and cheeks.

Dental Lamina

The dental lamina is the primordium for the ectodermal portion of the teeth. By the 8th week to 10th week of utero, a series of swellings (10 areas on each arch, corresponding to future deciduous central incisor to second deciduous molar) of the dental lamina (Fig. 3.3).

Later, during the development of the jaws, the permanent molars (4th month of utero for first permanent molar, first year of life for second permanent molar and 4-5 yrs. of life for third permanent molar) arise directly from a distal extension of the dental lamina.

The distal proliferation of the dental lamina is responsible for the location of the germs of the permanent molars in the ramus of the mandible and tubercity of maxilla.

The successors of the deciduous teeth develop from lingual extension of the free end of dental lamina opposite to the enamel organ of each deciduous tooth. (Fig. 3.4). The lingual extension of the dental lamina is named as successional lamina and develops from fifth month in utero (permanent central incisor, lateral incisor, canine, 1st premolar) to the tenth month of age (second premolar).

[Timing for initiation of tooth development

8th week to 10th week of utero	— Deciduous central incisor to deciduous second molar.
5th month of utero	— Permanent central incisor to first premolar.
10th month of life	— Second premolar.
4th month of utero	— First permanent molar.

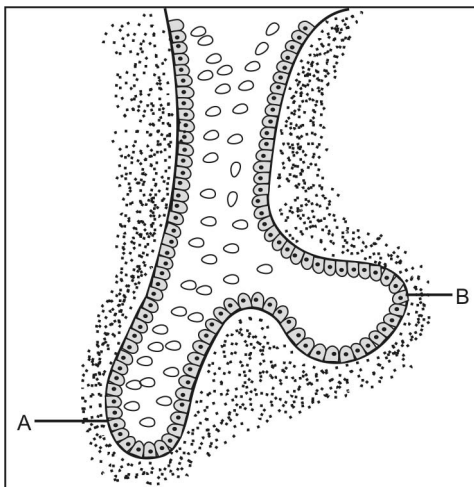


Fig. 3.2: The primary epithelial band divides into
A. buccally located vestibular lamina and
B. lingually located dental lamina

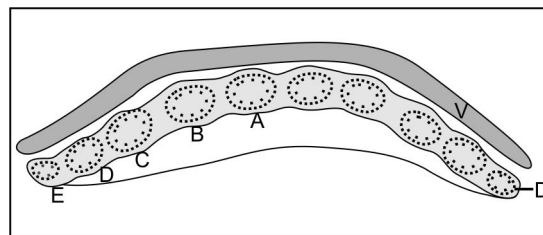


Fig. 3.3: Diagram to represent swelling in 10 areas in each arch corresponding to future deciduous tooth. V-vestibular lamina, D-dental lamina

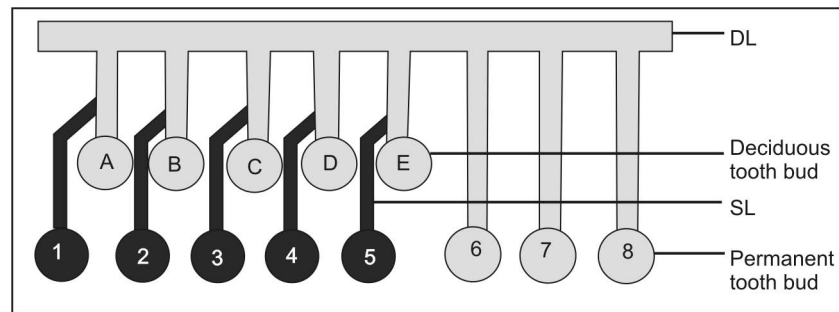


Fig. 3.4: Diagram to show the relationship between deciduous and permanent tooth bud. DL-Dental lamina, SL-Successional lamina, Deciduous tooth bud and permanent molar tooth bud arise from DL. Other permanent teeth arise from successional lamina

First year of life — Second permanent molar.
4-5 years of life — Third molar.]

Fate of Dental Lamina

It is evident that the total activity of dental lamina extends over a period of atleast 5 years. It is not equally active in all the region at the same time. The dental lamina may still be active in the third molar region after it has disappeared elsewhere. As the teeth continue to develop in early bell stage, the dental lamina, joining the tooth germ to oral epithelium breaks into discrete islands of epithelial cells by mesenchymal invasion, separating the developing tooth germ from oral epithelium. The clusters of epithelial cells normally degenerate and are resorbed. If they escape degeneration, they may form small cyst (eruption cyst) over developing tooth and delay eruption or the remnants of dental lamina persist as epithelial pearl within the jaws as well as in gingiva. The epithelial pearls are known as cell rests of Serre.

Different Stages of Tooth Development

Within the dental lamina, continued and localized proliferative activity leads to the formation of a series of epithelial ingrowths into the ectomesenchyme at the sites corresponding to the positions of ten maxillary and ten mandibular deciduous teeth. At this time the mitotic index and the growth of the epithelial cells are significantly lower than corresponding index in the underlying ectomesenchyme, which suggests that part of the 'ingrowth' is achieved by ectomesenchymal upgrowth. The epithelial downgrowth is known as enamel organ.

All the enamel organs do not develop at the same time and the first tooth to appear are those of the anterior mandibular region.

Although tooth development is a continuous process, it is divided into several morphologic stages. They are named after the shape of the enamel organ and are called—

1. The bud stage—(stage of initiation)
2. The cap stage—(stage of proliferation)
3. The early bell stage—(stage of morphodifferentiation and stage of histodifferentiation)
4. The late bell stage—(stage of apposition)

Bud stage—(stage of Initiation)

The bud stage is represented by the first epithelial incursion into the ectomesenchyme of the jaw. The ectodermal component in the bud stage appears as a simple, spherical to ovoid epithelial condensation (resembling a bud) which is poorly morphodifferentiated and histodifferentiated. (show little change in shape and function).

It consists of peripherally located low columnar cells and centrally located polygonal cells. The cells of the tooth bud have a higher RNA content, a lower glycogen content and an increased oxidative enzyme activity. The cells are separated from underlying ectomesenchyme by a basement membrane.

There is condensation of ectomesenchymal cells adjacent to the bud (Fig. 3.5).

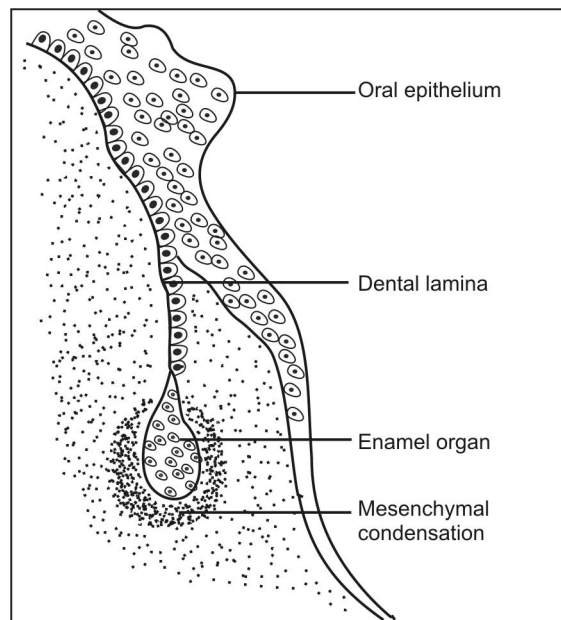


Fig. 3.5: Bud stage

Cap Stage—(stage of proliferation)

By the 11th week of utero epithelial bud continues to proliferate into the ectomesenchyme. The epithelial ingrowth which superficially resembles a cap is called Enamel Organ or Dental Organ. Among other functions it eventually forms enamel of the tooth.

Adjacent to the concave portion of the enamel organ there is condensation of ectomesenchyme. This condensation of cells results from failure to produce extracellular substance and thus not separated from each other. The condensed ectomesenchymal cells are called Dental Papilla which forms dentin and pulp. The condensed ectomesenchyme limiting the dental papilla and encapsulating the enamel organ is known as Dental follicle or Dental Sac. It gives rise to cementum, periodontal ligament and alveolar bone. (Fig.3.6).

The enamel organ or dental organ at this stage consists of distinct cell layers—

1. *Outer enamel (Dental) epithelium*—These are cuboidal cells covering the convexity of the cap. They are separated from dental follicle by delicate basement membrane and

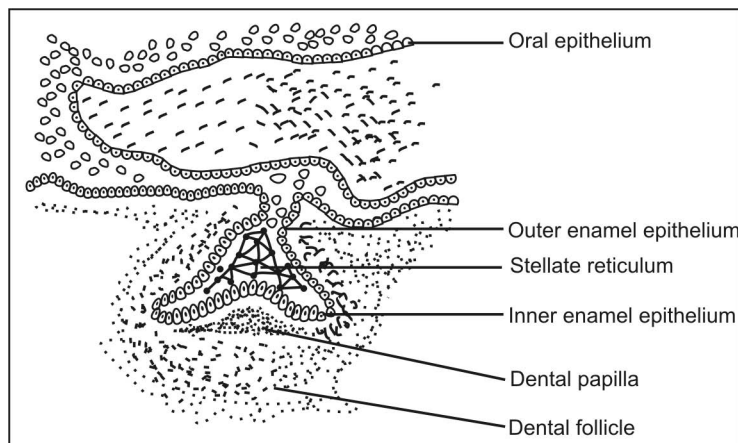


Fig. 3.6: Cap stage

hemidesmosomes anchor the cells to the basal lamina. The cells of the outer enamel epithelium contain large centrally placed nucleus. Organelles associated with protein synthesis (e.g. endoplasmic reticulum, golgi material, mitochondria) are present in small amount.

Functions—

They are involved (a) in the maintenance of the shape of the enamel organ. (b) in the exchange of substances between enamel organ and surrounding tissues.

2. *Inner enamel (Dental) epithelium*—The cells at the concavity of cap of enamel organ are tall, columnar and are known as inner enamel epithelium. They show an increase in RNA content, hydrolytic and oxidative enzyme activity. They are separated from dental papilla by basement membrane.

Function—

In later stages, they are transformed into enamel forming cells, the Ameloblast.

3. *Stellate reticulum*—They are polygonal cells located in the center of the enamel organ. They synthesize and secrete glycosaminoglycans into extracellular compartment between the cells. Glycosaminoglycans are hydrophilic, so pull water into enamel organ. The increasing amount of fluid increases the volume of the extracellular compartment of enamel organ and the cells are forced apart. Because the cells retain connections with each other through their desmosomal contacts, they become star shaped. So the central part of enamel organ is known as stellate reticulum. The cell bodies contain large nucleus with many branching processes. In addition to glycosaminoglycans the cells also contain alkaline phosphatase, but small amounts of RNA and glycogen.

Functions—(a) It gives a cushion like consistency that may support and protect the delicate enamel-forming cells.

(b) It gives nutrition to the enamel forming cells.

Early Bell Stage—(Stage of Morphodifferentiation and Histodifferentiation)

By the 14th week of development, the tooth germ continues to grow to the next stage of tooth development, the bell stage. (Fig. 3.7). It is so called because the enamel organ resembles the shape of a bell as the undersurface of the epithelial cap deepens.

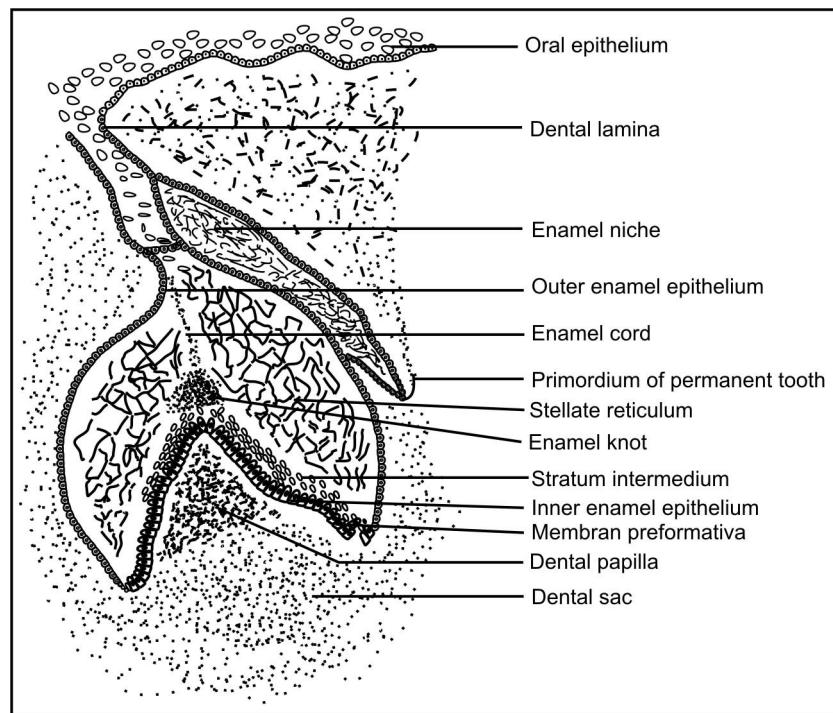


Fig. 3.7: Early Bell stage

In this stage, the dental lamina joining the tooth germ to the oral epithelium breaks up into discrete islands of epithelial cells, thus separating the developing tooth from oral epithelium.

Enamel organ in Early Bell stage

1. *Inner enamel epithelium*—The cells of this layer are columnar at early bell stage. They have a centrally placed nucleus and cytoplasm contains free ribosomes, scattered rough endoplasmic reticulum, evenly dispersed mitochondria, some tonofilaments, a golgi complex. The cells are connected by desmosomal connections. They are rich in RNA and glycogen but do not contain alkaline phosphatase. The cells lie between two opposing pressures of stellate reticulum and growing dental papilla and are in a state of equilibrium.

Morphodifferentiation—The configuration of the inner enamel epithelium broadly maps out the occlusal pattern of the tooth. This folding is related to differential mitosis along the inner enamel epithelium. The future cusps and incisal margin are sites of precocious cell maturation associated with cessation of mitosis, while areas corresponding to the fissures and margins of the tooth remain mitotically active (Fig. 3.8).

The differential cell division of inner enamel epithelium clearly demarcates the crown pattern of the tooth germ and it is known as morphodifferentiation.

2. *Stratum Intermedium*—These cells first appear at the early bell stage and consists of two or three layers of flattened cells lying over the inner enamel epithelium. The cells of the stratum intermedium resemble the cells of the stellate reticulum, although the intercellular spaces are smaller and the cells contain more alkaline phosphatase.

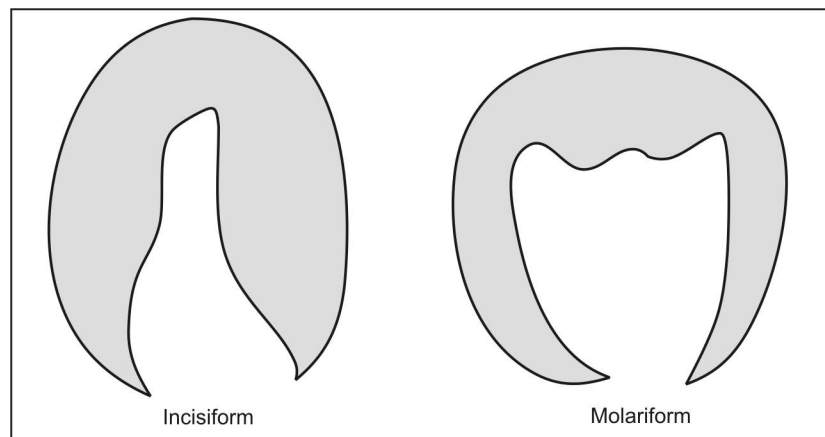


Fig. 3.8: Differential cell division of internal enamel epithelium determines crown pattern

Function—The stratum intermedium is concerned with

- a. the synthesis of protein.
(Inner enamel epithelium cannot form enamel without stratum intermedium as they lack alkaline phosphatase. Both the layers are considered as a single functional unit for the formation of enamel.)
- b. the transport of materials to and from the ameloblasts.
- c. concentration of materials.

3. *Stellate reticulum*

This tissue is most fully developed at the Bell stage. Certain transient structures are developed in enamel organ. They are—(Fig. 3.9)

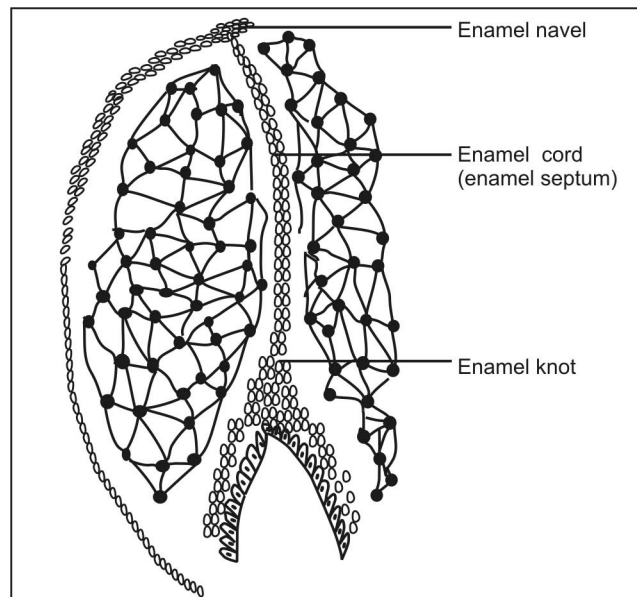


Fig. 3.9: Part of enamel organ in early Bell stage

- a. *Enamel knot*—It is a localized mass of cells produced by a rapid multiplication of cells in the center of the inner enamel epithelium. It forms a bulge into the dental papilla, at the center of the enamel organ. It was once thought that the enamel knot played a role in the formation of crown pattern by outlining the central fissure. But its role is unknown as it disappears very soon. It contributes cells to the enamel cord.
- b. *Enamel cord*—It is a strand of cells extending from enamel knot to stellate reticulum. It overlies the incisal margin of a tooth or to the apex of the first cusp to develop. The cells of the enamel cord are distinguished from their surrounding stellate reticulum cells by their elongated nuclei. It is a focus for the origin of stellate reticulum cells.
- c. *Enamel septum*—When the enamel cord completely divides the stellate reticulum into two parts, reaching the outer enamel epithelium, it is termed enamel septum.
- d. *Enamel navel*—Where the enamel cord meets the outer enamel epithelium, a small invagination is termed enamel navel.
- e. *Enamel niche*—It is an apparent structure in histologic sections, created because the dental lamina is a sheet rather than a single strand and often contains a concavity filled with connective tissue. A section through this arrangement creates the impression that the tooth germ has a double attachment to the oral epithelium by two separate strands. These strands enclose a funnel-shaped depression containing connective tissue, which is termed the enamel niche. (Fig.3.10). Its significance is unknown.

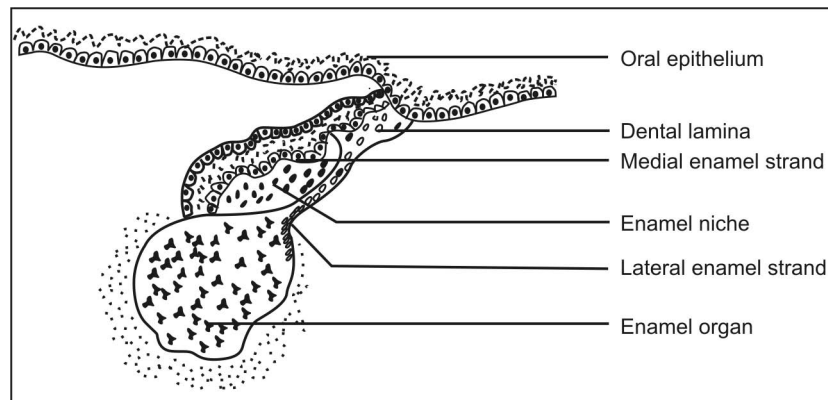


Fig. 3.10: Enamel niche

4. *Outer enamel epithelium*—The cells of the outer enamel epithelium flatten to a low cuboidal form. The inner enamel epithelium meets the outer enamel epithelium at the rim of the enamel organ. This junctional zone is known as cervical loop (Fig. 3.11).

Dental papilla—The dental papilla consists of closely packed mesenchymal cells with only a few delicate extracellular fibrils. Histochemically, the dental papilla becomes rich in glycosaminoglycans.

Dental follicle—Interposed between the enamel organ and the wall of the developing bony crypt is the mesenchymal tissue of the dental follicle. (Fig. 3.12). It has three layers. The inner investing layer is a vascular, fibrocellular condensation, three to four cells thick, immediately surrounding the tooth germ. The nuclei of the cells tend to be elongated circumferentially. This layer is responsible for formation of cementum. The outer layer of

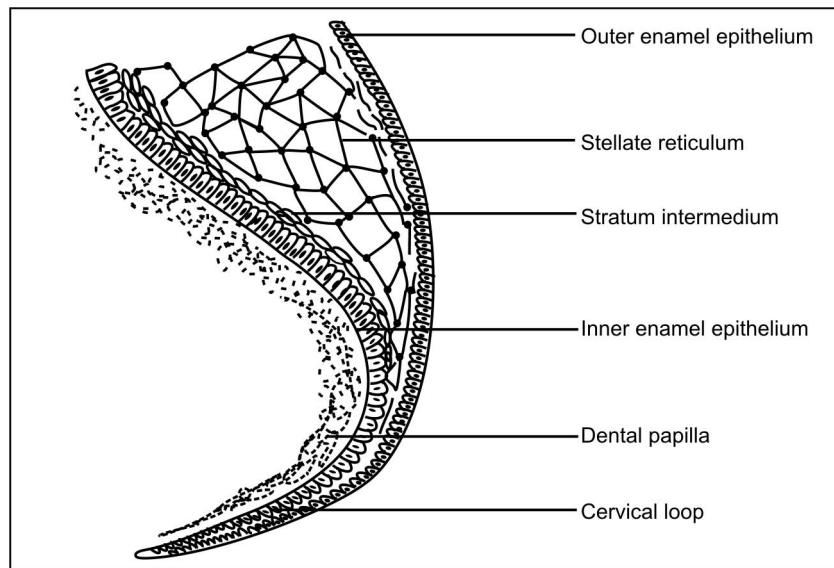


Fig. 3.11: Cervical loop

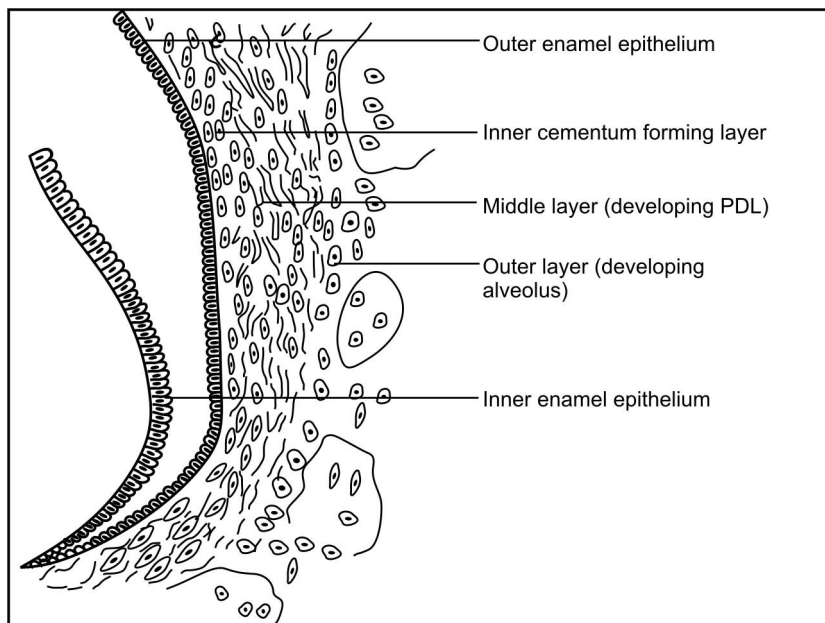


Fig. 3.12: Dental follicle

the dental follicle is represented by a vascular mesenchymal layer which lines the developing alveolus. Between the two layers is loose connective tissue with no marked concentration of blood vessels. This layer forms the periodontal ligament.

Histodifferentiation of Tooth Germ Prior to Enamel and Dentin Formation

Prior to amelogenesis (enamel formation) the cells of the inner enamel epithelium differentiate into tall columnar cells called ameloblasts. These cells are 4 to 5 μm in diameter and about 40 μm high.

Before enamel formation begins, the stellate reticulum collapses, reducing the distance between the ameloblasts and the nutrient capillaries near outer enamel epithelium. This change begins at the height of the cusp or incisal edge and progresses cervically.

Prior to enamel and dentin formation the outer enamel epithelium is laid in folds. Between the folds the adjacent mesenchyme of the dental follicle forms papillae that contain capillary loops and thus provide a rich nutritional supply for the intense metabolic activity of the avascular enamel organ. Once enamel and dentin deposition start, nutritional supply from dental papilla can not reach the enamel forming cells. So the change in stellate reticulum and outer enamel epithelium facilitate the reversal of nutrition from dental follicle.

The cells of the inner enamel epithelium exert an organizing influence on the underlying mesenchymal cells in the dental papilla, which later differentiate into odontoblast, the dentin forming cells.

The basement membrane that separates the enamel organ and the dental papilla just prior to dentin formation is called the membrana preformativa (shown in Fig. 3.7).

Advanced Bell Stage (Late Bell Stage or Stage of apposition)—This stage is associated with the formation of the dental hard tissues, commencing at about 18th week of utero.

Under the inductive influence of developing ameloblasts (pre-ameloblasts), the adjacent mesenchymal cells of the dental papilla become columnar and differentiate into odontoblasts (Figs 3.13 and 3.14).

The odontoblasts then lay down a layer of dentin along membrana preformativa.

The dentin induces the ameloblasts to secrete enamel. The boundary between the enamel and dentin forms dentinoenamel junction.

The formation of hard tissues gradually progresses from future incisal edge or tip of the cusp to cervix and from dentinoenamel junction to outer periphery in case of enamel and in reverse direction in case of dentin (Fig.3.15).

The cervical portion of enamel organ gives rise to epithelial root sheath of Hertwig, which acts as a scaffold for root formation.

Formation of Root

The development of the roots begins after enamel and dentin formation has reached the future cementoenamel junction.

At early bell stage inner and outer enamel epithelium meet at the rim of the enamel organ to form cervical loop. The epithelial cells of inner and outer enamel epithelium of cervical loop proliferate to form a double layered sheath around the dental papilla between the papilla and the dental follicle. The sheath is known as Hertwig's epithelial root sheath. It moulds the shape of the roots and initiates radicular dentin formation.

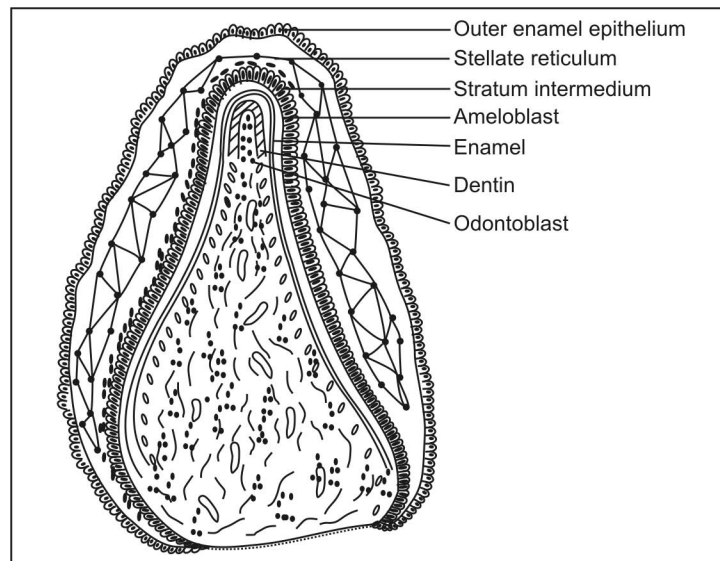


Fig. 3.13: Late Bell stage

The outer and inner enamel epithelium bend at the future cemento-enamel junction into a horizontal plane, narrowing the wide cervical opening of tooth germ. This rim of the root sheath, the epithelial diaphragm encloses the primary apical foramen (Fig. 3.15).

As the inner epithelial cells of root sheath progressively enclose more and more of the expanding dental papilla, they initiate the differentiation of odontoblasts from the cells at the periphery of the dental papilla. The cells eventually form dentin of the root. Once the first layer of radicular dentin is laid down, the epithelial root sheath loses its structural continuity. It fragments

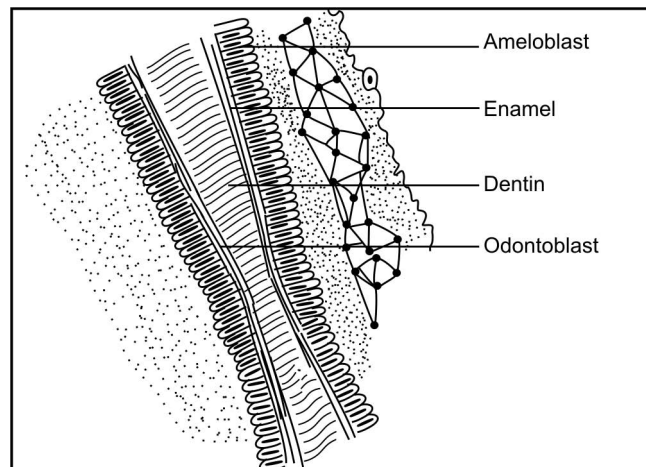


Fig. 3.14: Part of developing tooth at late Bell stage.
Higher magnification of 3.13 to show odontoblast

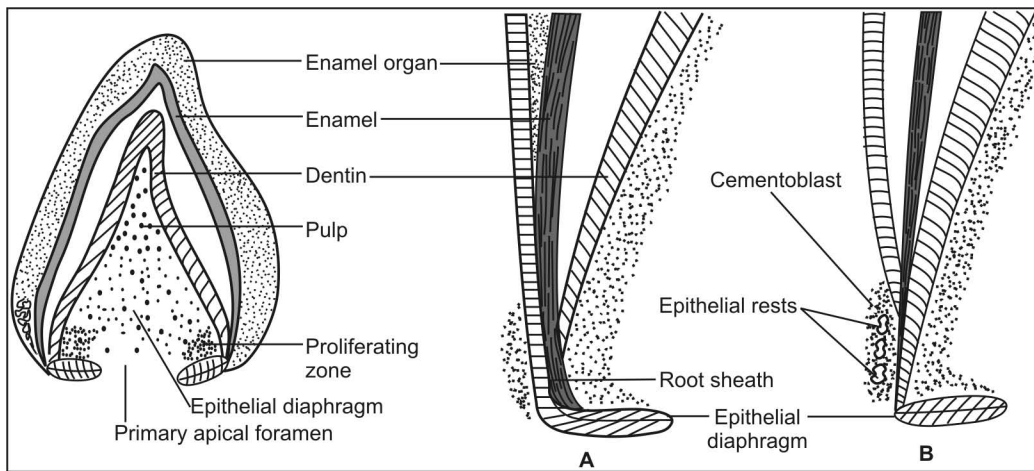


Fig. 3.15: Formation of hard tissue progresses from incisal edge to cervix. Formation of epithelial diaphragm and primary apical foramen

Fig. 3.16: **A.** Elongation of Hertwig's epithelial root sheath coronal to diaphragm, **B.** Root sheath is broken into epithelial rest, differentiation of cementoblast

to form a fenestrated network around the tooth. Through the break in the root sheath, the newly formed dentin come in direct contact with the connective tissue of the dental follicle (Figs 3.16A and B).

Under the influence of dentin, cells of the dental follicle are differentiated into cementoblasts which are responsible for formation of cementum. This initiates the formation of root of single-rooted tooth.

In case of multi-rooted tooth, the differential growth of the epithelial diaphragm causes the division of the root trunk into two or three roots. During the general growth of the enamel organ the expansion of its cervical opening occurs in such a way that long tongue like extensions of the horizontal diaphragm develop. (Figs 3.17A to C). Two such extensions are found in the germs of tooth having two roots and three in the germs of teeth having three roots.

Before division of the root trunk occurs, the free ends of these horizontal epithelial flaps grow toward each other and fuse. The single cervical opening of the coronal enamel organ is then divided into two or three openings. On the pulpal surface of the dividing epithelial bridges, dentin formation starts and on periphery of each opening root development follows in the same way as single-rooted tooth.

Growth of Root

The plane of the diaphragm remains relatively fixed during the development and growth of the root. With the onset of root formation, as gradually dentin and cementum are deposited, the crown of the tooth is growing away from the bony base of the crypt, and the root sheath is not actually growing into jaw. (Fig. 3.18) So with the elongation of the root, crown moves in upward direction and the plane which was once the cervical region gradually forms wide apical foramen. Later it is further narrowed by apposition of dentin and cementum to the apex of the root.

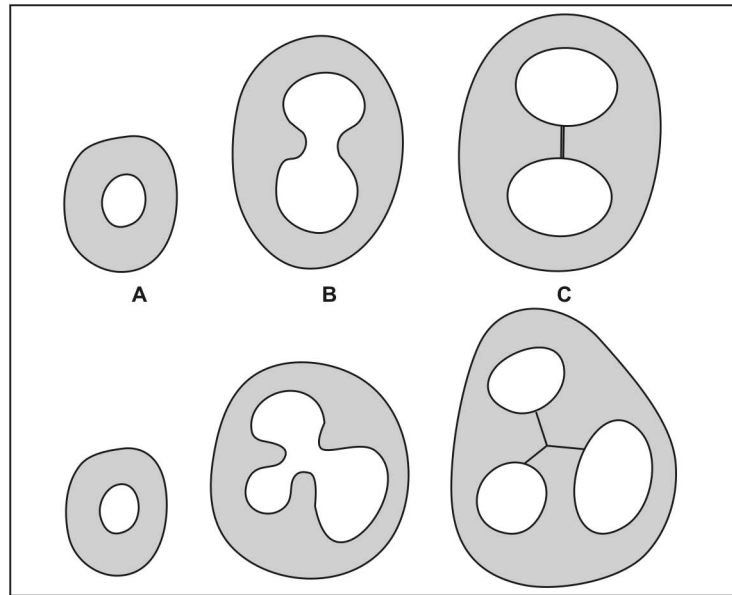


Fig. 3.17: Surface view of epithelial diaphragm **A.** Simple diaphragm, **B.** Tongue like extensions of epithelial diaphragm proliferate, **C.** The flaps unite and divide single cervical opening into two or three openings

Fate of the Hertwig's Epithelial Root Sheath

The Hertwig's epithelial root sheath loses its structural continuity after the first layer of radicular dentin is laid down. Its remnants persist as an epithelial network of strands or tubules near the external surface of root. These epithelial remnants are found in the periodontal ligament of erupted teeth and are called cell rests of Malassez. Although apparently functionless, they are the source of the epithelial lining of dental cysts that develop in reaction to inflammation of the periodontal ligament.

Clinical Consideration

1. Tooth may develop in abnormal location like in ovary as in dermoid tumors or cysts or in the hypophysis. This happens as dental papilla mesenchyme can induce tooth epithelium to form enamel.

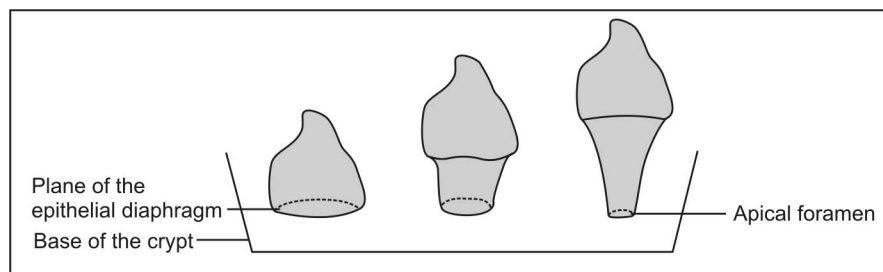


Fig. 3.18: Crown moves in upward direction with elongation of root

2. Anodontia—Absence of single or multiple teeth due to lack of initiation of tooth forming epithelium is anodontia and most frequently occur in relation to permanent maxillary lateral incisor, third molar, mandibular second premolar.
3. Supernumerary tooth—Abnormal initiation may result in development of single or multiple supernumerary teeth.
4. Disturbances in morphodifferentiation may affect the form and size of the tooth, e.g.—congenital syphilis may lead to mulberry molar, peg-shaped lateral incisor.

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4

Development of Oro-Dental Hard Tissues

The development of hard tissues consists of two phases—

1. Initially, there is extracellular secretion of an organic matrix.
2. In the next phase, there is deposition of mineral (primarily in the form of calcium hydroxyapatite crystals) within organic matrix surrounding a nucleus.

Difference in the processes of mineralization between enamel and other hard tissues (dentin, cementum and bone).

<i>Enamel</i>	<i>Dentin, cementum, bone</i>
1. Only dental hard tissue which is ectodermally derived.	1. Derived from ectomesenchymal tissue.
2. Organic matrix is composed of protein and is not collagenous in nature	2. Organic matrix is collagenous in nature.
3. Initial mineralization of enamel matrix takes place almost simultaneously with organic matrix deposition. Thus unmineralized layer of organic matrix is not found.	3. There is a lag period between matrix formation and mineralization, resulting in presence of a layer of unmineralized organic matrix, a few micrometers thick
4. The organic matrix of enamel is removed during the final mineralization phase (maturation), leaving less than 1% by weight of organic matrix in fully formed enamel.	4. The organic matrix of dentin, cementum and bone forms a substantial part of mineralized tissue.

AMELOGENESIS-(DEVELOPMENT OF ENAMEL)

The deposition of enamel begins at the late bell stage, immediately after dentinogenesis has commenced.

[Ameloblasts are differentiated from inner enamel epithelium. Under the inductive influence of ameloblasts, the adjacent ectomesenchymal cells of dental papilla are differentiated to odontoblasts which lay down a layer of dentin along membrana preformativa. The dentin then induces the ameloblasts to initiate their secretory activities].

Life Cycle of the Ameloblasts

An understanding of amelogenesis is best approached by outlining the life cycle of the ameloblasts. It is divided into six stages—

1. *Morphogenic stage*—The differential cell division of inner enamel epithelium and their interaction with adjacent ectomesenchyme determine the crown pattern of the tooth germ.
The inner enamel epithelial cells are short columnar with large oval nuclei that almost fill the cell body (Fig. 4.1a).
The golgi apparatus and the centrioles are located in the proximal end (towards stratum intermedium) of the cells.
The mitochondria and other cytoplasmic components are evenly dispersed throughout the cytoplasm.
During ameloblast differentiation, mitochondria migrate to basal region of the cells and terminal bars appear. They are the point of close contact between the cells. They comprise thickening of the opposing cell membranes associated with condensation of underlying cytoplasm.
2. *Organizing stage*—The inner enamel epithelium interacts with the adjacent connective tissue which differentiate into odontoblast.
The inner enamel epithelium becomes longer, and the nucleus-free-zones at the distal end of the cells become as long as the proximal part containing the nuclei (Fig. 4.1b).
There is migration of centrioles and Golgi apparatus from the proximal end of the cells into their distal end.
Fine acidophilic granules (E.M. Study reveals them as mitochondria) are concentrated in basal or proximal part of cell.
During the terminal phase of organizing stage, the odontoblasts lay down the first layer of dentin. There is reversal of nutritional source for ameloblasts as they can no more receive nutrient material from blood vessels of dental papilla. The capillaries of the dental sac proliferate into the corrugated folds of outer enamel epithelium. The stellate reticulum collapses, reducing the distance between the ameloblasts and nutrient capillaries. The change in stellate reticulum and outer enamel epithelium facilitate the reversal of nutrition from dental follicle.
In the initial stages of enamel formation until the collapse of the enamel organ, ameloblasts utilize the stored glycogen, accumulated before beginning their secretory activity.
3. *Formative stage*—In formative stage, the ameloblasts are 4 to 5 μm in diameter and about 40 μm in height.
The ameloblasts enter their formative stage after the first layer of dentin has been formed.
The earliest apparent change is the development of blunt cell processes on the ameloblast surfaces, which penetrate the basal lamina and enter the predentin (Fig. 4.1c).
4. *Maturation stage*—Enamel maturation (full mineralization) occurs after most of the thickness of the enamel matrix has been formed in the occlusal or incisal area. In the cervical parts of the crown, enamel matrix formation is still progressing. At this stage, the cells of the stratum intermedium lose their cuboidal shape and regular arrangement and assume a spindle shape. Ameloblasts play a part in the maturation of enamel. They are slightly reduced in length and are closely attached to the enamel matrix. They display microvilli at their distal extremities, and cytoplasmic vacuoles containing material resembling enamel matrix are present (Fig. 4.1d). These structures indicate an absorptive function of these cells.
5. *Protective stage*—After complete calcification of enamel, the ameloblast cell layer can not be differentiated from stratum intermedium and outer enamel epithelium. The three cell layers form a stratified epithelial covering of the enamel, the reduced enamel epithelium (Fig. 4.1e)

The function of the reduced enamel epithelium is to protect the mature enamel by separating it from surrounding connective tissue until the tooth erupts. If the connective tissue comes in contact with the enamel, it may be either resorbed or covered by a layer of cementum.

During this phase of the life cycle of ameloblasts, the epithelial enamel organ may retract from the cervical edge of the enamel. The adjacent mesenchymal cells may then deposit afibrillar cementum on the enamel surface.

6. *Desmolytic stage*—The reduced enamel epithelium—

- a. proliferates, inducing atrophy of the connective tissue separating it from oral epithelium.
- b. elaborates enzymes which destroy the connective tissue fibers by desmolysis.

After the desmolysis of connective tissue, the reduced enamel epithelium fuses with oral epithelium and it facilitates eruption of tooth (Fig. 4.1f).

Premature degeneration of reduced enamel epithelium may prevent the eruption of a tooth.

Prerequisite for Amelogenesis

- a. Differentiation of inner enamel epithelium to ameloblasts.
- b. Deposition of dentin as a phase of reciprocal induction.
- c. High alkaline phosphatase activity of stratum intermedium.
- d. Reversal of nutritional source.

On the basis of ultrastructure and composition, two processes are involved in the development of enamel: a) organic matrix formation and b) mineralization.

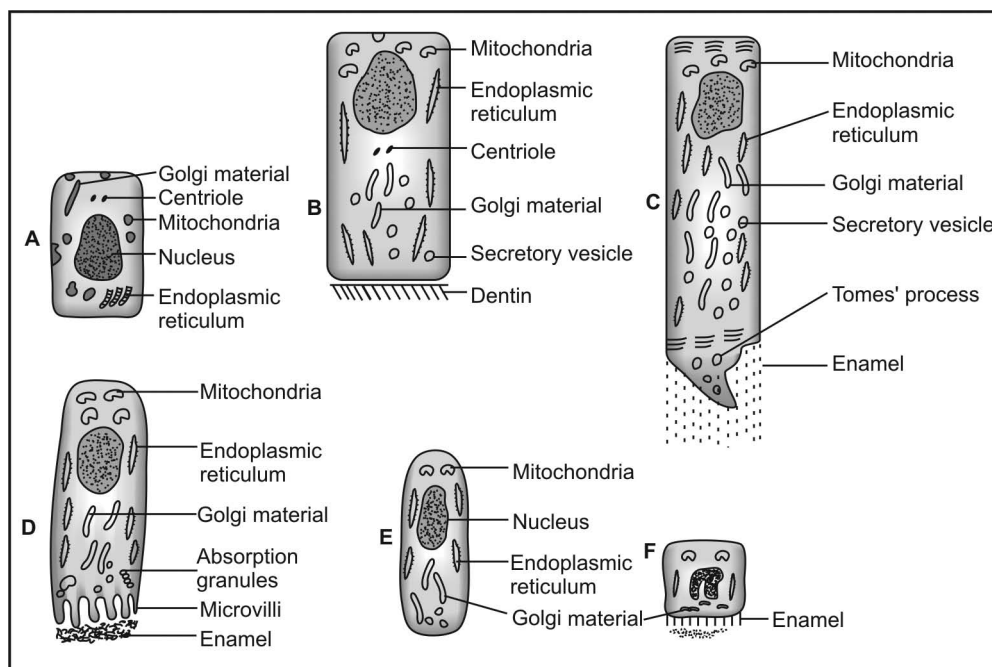


Fig. 4.1: a. Morphogenic stage; b. Organizing stage; c. Formative stage; d. Maturation stage; e. Protective stage; f. Desmolytic stage

Formation of Enamel Matrix

After a small amount of dentin has been laid down, the ameloblasts lose the projections that had penetrated the basal lamina separating them from predentin and the islands of enamel matrix are deposited along the predentin. The matrix immediately becomes partially mineralized.

The organic matrix consists of enamel proteins, an array of enzymes including serine proteases, metalloproteases and phosphatases, and traces of other proteins analogous to various glycosylated, sulfated, and phosphorylated non collagenous proteins found in the calcifying connective tissues. Of the enamel proteins, 90 percent are a heterogeneous group of gene-specific, low molecular weight proteins known as amelogenins. The remaining 10 percent of enamel protein consists of enamelin, tuffelin and amelin.

As enamel deposition proceeds, a thin continuous layer of enamel is formed along the dentin. This junction is termed as the dentinoenamel membrane. Its presence accounts for the fact that the distal ends of the enamel rods are not in direct contact with the dentin.

Tomes' Processes

As the first increment of enamel is formed, the ameloblasts begin to move away from the dentin surface. As a result of that, each cell forms a conical projection. These projections are called Tomes' processes (Fig. 4.2) which jut into the newly formed enamel giving the junction between the enamel and the ameloblast a picket-fence or saw-toothed appearance. The interdigitation is due to the fact that the long axes of the ameloblasts are not parallel to the long axes of the rods.

Distal terminal bars: They are localized condensations of cytoplasmic substance, closely associated with the thickened cell membranes, appear at the distal ends of the ameloblasts, separating the Tomes' processes from the cell proper. They are observed during the enamel producing stage of the ameloblast. Their exact function is not known.

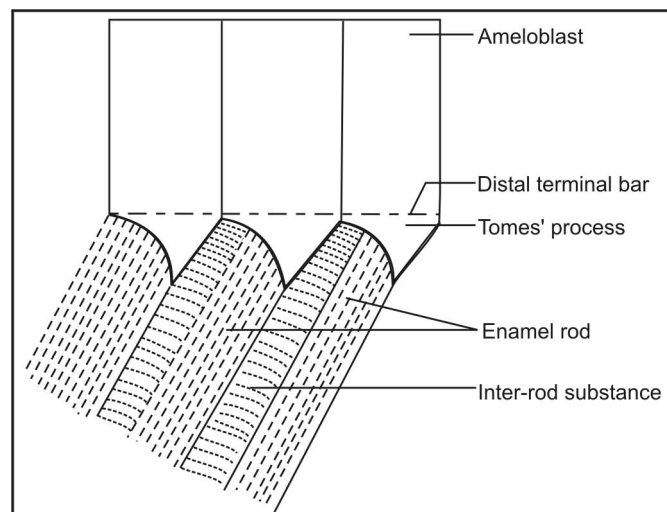


Fig. 4.2: Relationship between Tomes' processes and enamel prism formation

Mineralization and Maturation of the Enamel Matrix

In the first stage, an immediate partial mineralization occurs in the enamel matrix. The initial influx may amount to 25 to 30% of the eventual total mineral content.

As enamel protein is deposited directly on mineralized dentin, the first enamel crystallites are nucleated by apatite crystallites located within dentin. Enamel protein tuffelin also acts as a nucleator for the first enamel crystal.

Enamel crystallites grow rapidly in length within the organic matrix, until the entire thickness of enamel has laid down.

The second stage, or maturation, is characterized by the gradual completion of mineralization. The process of maturation starts from the height of the crown and progresses cervically. However, at each level, maturation seems to begin at dentinal end of the rods. Each rod matures from the depth to the surface, and the sequence of maturing rods is from cusps or incisal edge toward the cervical line (Fig. 4.3A to D).

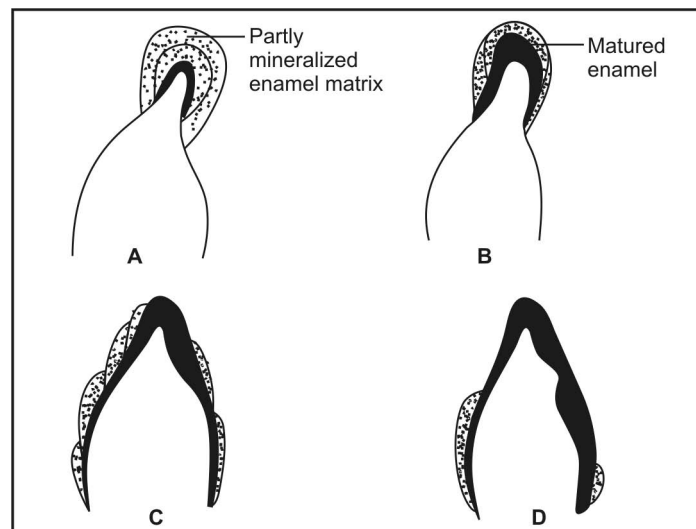


Fig. 4.3A to D: Pattern of mineralization and maturation of enamel

As much maturation proceeds, the ribbon-shaped crystals increase in thickness and width. Concomitantly the organic matrix gradually become thinned to make room for growing crystals. The loss of organic matrix is caused by withdrawal of a substantial amount of protein as well as water. Mostly the amelogenins and its degraded products are squeezed out from between the growing crystals leaving behind a thin organic matrix surrounding the crystallites in fully mature enamel matrix.

Ameloblasts Covering Maturing Enamel

The ameloblasts over maturing enamel are short and have villous surface near the enamel. The ends of the cells are packed with mitochondria and are responsible for transporting organic components from the matrix.

One interpretation of the relationship between the keyhole-shaped enamel rods and the roughly hexagonal ameloblasts, is that each enamel rod is formed by four ameloblasts and each ameloblast contributes to four different rods. (Fig. 4.4). The bulk of the “head” of each rod is formed by one ameloblast, where as three others contribute to the “tail” of each rod.

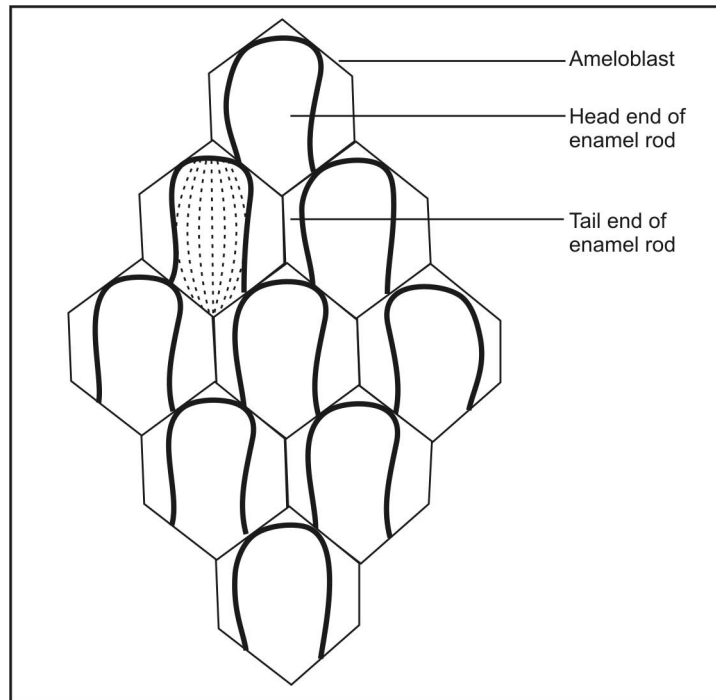


Fig. 4.4: One interpretation of relationships between enamel rods and ameloblasts

Clinical Consideration

1. *Enamel hypoplasia*

It is the defect in matrix formation of enamel and manifested by pitting, furrowing or even total absence of enamel.

2. *Enamel hypocalcification*

It is characterized by the formation of normal amount of enamel matrix which is not fully matured. It appears dull, opaque white and it is easily discolored, abraded by mastication or peeled off in layers. The defective enamel formation is known as Amelogenesis Imperfecta.

Dentinogenesis (Development of Dentin)

Odontoblasts are highly specialized connective tissue cells that differentiate from the peripheral cell layer of dental papilla under the influence of ameloblast (Fig. 4.5).

The odontoblasts are columnar in shape with 40 μm in length and 7 μm in width. The nucleus is basally placed. (Fig. 4.6). There is a large supranuclear Golgi material and a profuse rough endoplasmic reticulum.(Fig. 4.7A). A series of processes develop at the distal end of the cell (Fig. 4.7B). One process becomes more pronounced and it is through this that the matrix is secreted (Fig. 4.7C).

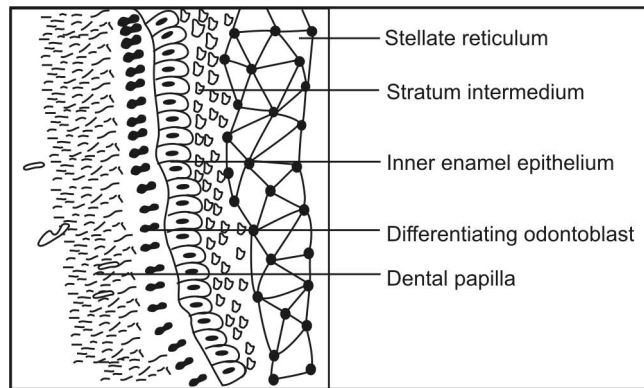


Fig. 4.5: Differentiation of odontoblast

Dentinogenesis is a two-phase sequence—

1. Formation of matrix
2. Mineralization
1. *Formation of matrix:* Initially collagen fibers are formed by subodontoblastic cells in the ground substance of pulp. Later odontoblasts secrete both collagen and intercollagen substance, proteoglycans.

Bundles of type 1–collagen (composed of large diameter fibrils-0.1 to 0.2 μm in diameter) formed by the activity of the cells of subodontoblastic layer, pass spirally between odontoblasts to fan out against the surface of basal lamina supporting the inner enamel epithelium (Fig. 4.8). The fibers are argyrophilic (Stain black with silver) and are known as Von Korff fibers. The fibers are deposited in structureless ground substance (acid mucopolysaccharide, carbohydrate and protein).

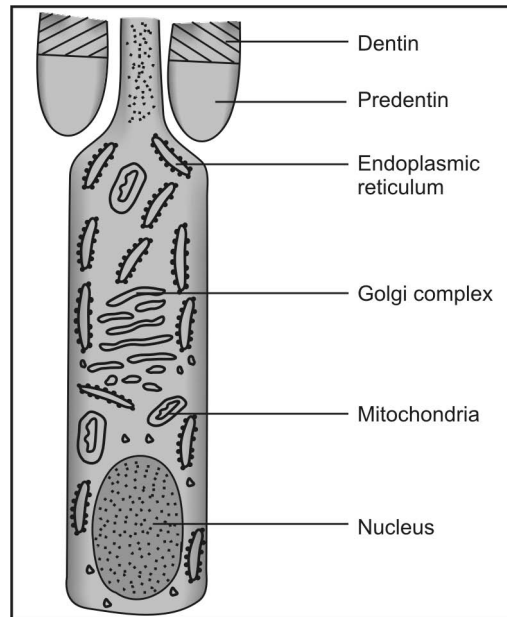


Fig. 4.6: Odontoblast

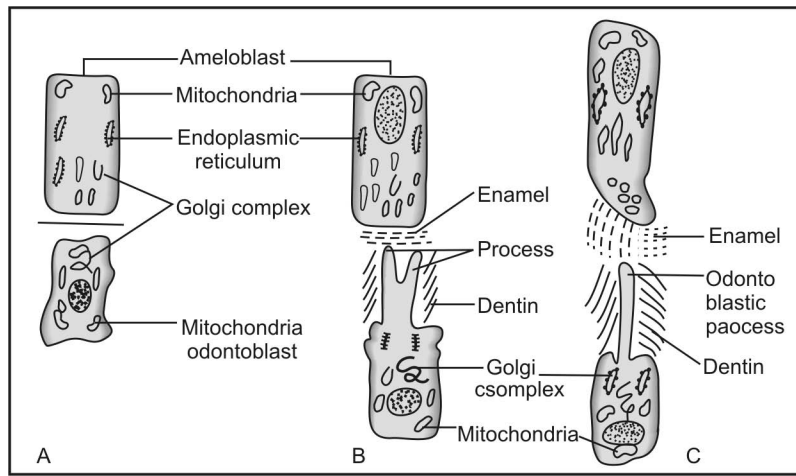


Fig. 4.7A to C: Life cycle of odontoblast

The Korffs fibers are intermingled with fine network of collagenous fibrils (formed by odontoblasts and have diameter of $0.05 \mu\text{m}$). The large collagen fibrils, together with the ground substance constitute the organic matrix of first formed or mantle dentin. [Electron microscopically the existence of Von Korff fibers are doubtful. It reveals that the silver staining is of ground substance among the cells and not collagen].

After deposition of matrix, the odontoblasts begin to move towards the pulp leaving behind an elongated process, the principal extension of the cell, the odontoblast process (Fig.4.9).

Initial daily increments of matrix deposition is approximately $4 \mu\text{m}$. This continues upto the stage of crown formation, eruption of teeth and movement of the teeth into occlusion. After this stage dentin production slows down to about $1 \mu\text{m}$ per day. After root formation dentin deposition may decrease further.

$2-6 \mu\text{m}$ wide, unmineralized matrix of dentin is always present along the pulp border as the deposition of mineral lags behind the formation of organic matrix.

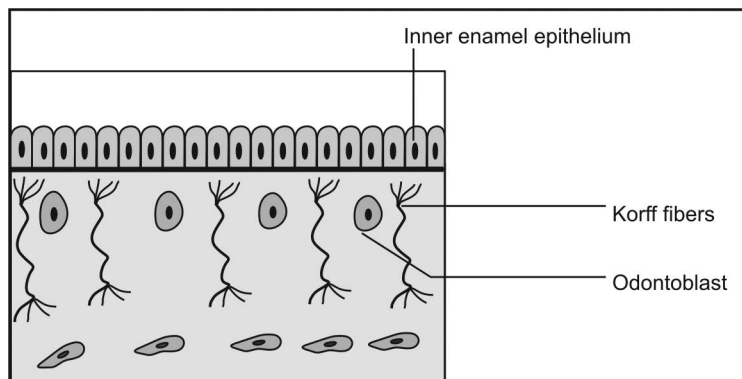


Fig. 4.8: Von Korff fibers

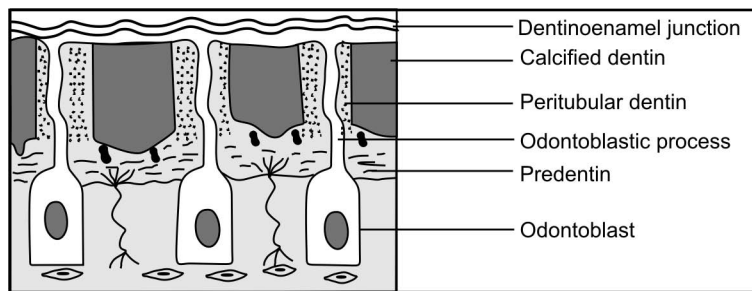


Fig. 4.9: Development of dentin

2. **Mineralization:** The earliest crystal deposition is in the form of very fine plates of hydroxyapatite on the surfaces of the collagen fibrils and in the ground substance with long axis of the crystals parallel to the fibril axis.

Mineralization also occurs by globular calcification. It involves the deposition of crystals in several discrete areas of matrix. With continued crystal growth, globular masses are formed, continue to enlarge and eventually fuse to form single calcified mass.

Throughout dentinogenesis, mineralization is achieved by continuous deposition of mineral, initially in the matrix vesicle and then at the mineralization front. Calcium channels of the L type are present in the basal plasma membrane of the odontoblast. The presence of alkaline phosphatase activity and Ca-ATPase activity at the distal end of the cell indicates a mechanism for the release of mineral from the cell.

Clinical Consideration

1. **Dentinogenesis imperfecta:** The condition of defective dentin formation is known as Dentinogenesis Imperfecta.
2. Exposed dentin should be sealed with non-irritating, insulating substance as thermal, bacterial, chemical or mechanical trauma may lead to damage of pulp.
3. Tubule system of dentin cause rapid spread of dental caries.

Cementogenesis (Development of Cementum)

Cementum formation in the developing tooth is preceded by the deposition of dentin along the inner aspect of Hertwig's epithelial root sheath. Once dentin formation is underway, breaks occur in the epithelial root sheath allowing the newly formed dentin to come in contact with the connective tissue of dental follicle and the cells of the follicle are induced to differentiate into cementoblast, the cementum forming cells.

Primary (Acellular) Cementum

Matrix formation: Much of the collagen in primary cementum is derived from Sharpey's fibers of the periodontal ligament and cementoblasts secrete little collagen.

The cementoblasts secrete ground substance as it contains intracytoplasmic organelles necessary for protein synthesis and secretion.

Mineralization: The presence of the hydroxyapatite crystals in the neighboring dentin initiates mineralization in cementum. Mineralization proceeds in a linear fashion. There is always a thin, unmineralized layer of precementum present on the developing surface of the cementum (Fig. 4.10).

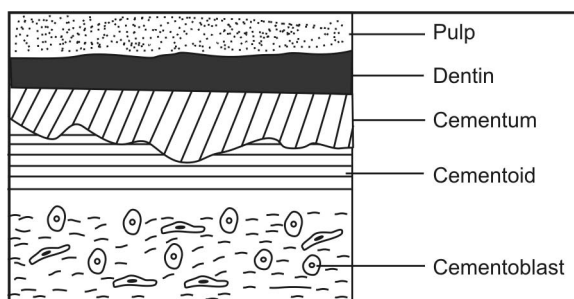


Fig. 4.10: Formation of acellular cementum

Secondary (Cellular) Cementum

Following the formation of primary cementum in the cervical portion of the root, secondary cementum appears in the apical region of the root (at about the time of eruption, when approximately two-thirds of the root has formed). Associated with the increased rate of formation, cementoblasts at the surface become incorporated into the forming matrix and are converted into cementocytes (Fig. 4.11).

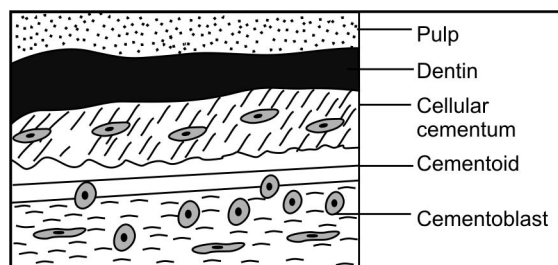


Fig. 4.11: Formation of cellular cementum

Matrix contains both extrinsic fibers from periodontal ligament (arranged perpendicular to root surface) secreted by cementoblasts.

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Enamel

Enamel is the most highly mineralized tissue, covering the anatomic crown of the tooth.

PHYSICAL CHARACTERISTICS

1. *Thickness*: The thickness varies over different parts of a tooth and from one type of tooth to another. It is thickest over the cusps of the molars where it measures about 2.5 mm and over incisal edge of incisors where it measures 2 mm. It thins down to knife edge at cervical margin and also thin at fissures and pits.
2. *Density*: It varies from 3.0 to 2.84 gm /ml. The density decreases from surface of enamel to dentino-enamel junction. The permanent teeth have more density than deciduous teeth. The density of enamel increases progressively during development. The final value is reached after eruption and further increases with absorption of mineral from saliva. The permanent upper incisors have the maximum density and premolars and lower incisors have the least.
3. *Color*: Enamel is semi translucent. The color depends on the thickness. It appears bluish white or grayish at the thick opaque areas and yellowish white at the thin areas reflecting underlying dentin. The enamel on deciduous teeth, being more opaque, appears much whiter.
4. *Hardness*: Enamel is the hardest calcified tissue in the human body because of its high content of mineral salts and their crystalline arrangement. The hardness varies from 5-8 moh (Diamond =10 moh). This property enables enamel to withstand the heavy loads of mastication and limit the amount of wear.
5. *Specific gravity*: The specific gravity of enamel is 2.8-3.1. This fact has been useful when separating enamel from dentin for analytical purposes.
6. *Permeability*: The enamel is selectively permeable. It possesses a submicroscopic pore system in interprismatic and intercrystal spaces, permitting complete or partial passage of certain molecules.
7. *Solubility*: Enamel dissolves in acid media. The solubility rate is influenced by certain ions and molecules such as fluorides, silver nitrate, zinc chloride, etc. The surface enamel is less soluble in acids than deeper enamel.
8. *Tensile strength and compressibility*: Enamel has a low tensile strength and has high modulus of elasticity. So it is rigid in structure but extremely brittle.
9. *Refractive index*: Enamel is a crystalline material and is birefringent, the crystals refracting light differently in different directions. The tissue has an average refractive index of 1.62.

CHEMICAL COMPOSITION

Mature enamel consists of mainly inorganic material and only a small amount of organic substance and water. The exact composition varies between teeth, within different parts of the same tooth and even between the core and periphery of the same prism. An estimate of their composition is as follows—

	<i>Weight</i>	<i>Volume</i>
Organic	1%	2%
Inorganic	96%	89%
Water	3%	9%

Inorganic Composition

The inorganic component is mainly calcium phosphate in the form of hydroxyapatite crystals ($\text{Ca}_{10}(\text{OH})_2(\text{PO}_4)_6$). The apatites are variable, depending on the amount and variety of ion content. Fluoride, carbonate, magnesium, potassium, sodium, strontium, radium, vanadium can replace phosphate to modify the apatite crystal. Fluoride makes enamel more resistant to acid and is anti cariogenic.

Organic Composition

The organic matter increases towards dentino-enamel junction and is least at the surface. The organic content of the deciduous teeth is slightly higher than that of the permanent series. A fine, lacy network of organic material appears between the hydroxyapatite crystals. Two groups of proteins are found in developing enamel and often collectively known as enamelin.

1. *Amelogenins*: These are rich in proline. They are gradually removed during the enamel's development. Mature enamel contains degradation products of amelogenins.
2. *Non-amelogenins*: They are rich in glycine and aspartic acid. They are present in mature enamel.

Enamel proteins do not appear to be fibrous and they form relatively structureless gel. Chemical analyses of the organic matrix of mature enamel indicate that the amino acid composition is not closely related to keratin and is distinctly different from collagen. Roentgen-ray diffraction studies reveal that the molecular structure is typical of the group of proteins called cross- β -proteins. Histochemical reactions have suggested that the enamel forming cells of developing teeth contain a polysaccharide-protein complex. The presence of other organic elements such as lipids is controversial.

Structure of Enamel

Enamel, having high mineral content, is studied in prepared ground section and under light microscope by means of transmitted light. Enamel is composed of the following:

1. Enamel rods (prisms)
2. Rod sheaths
3. Cementing interrod substance.

Enamel Rods-Under Light Microscope

In longitudinal section under light microscope, the basic structural unit of enamel, the rods, are aligned perpendicularly to dentino-enamel junction, follow wavy course through one-third of enamel and then follow a direct path to the external surface of enamel (Fig. 5.1). The number of enamel rods has been estimated as ranging from 5 million in lower lateral incisors to 12 million in the upper first molars. The length of most rods is greater than the thickness of enamel because of oblique direction and wavy course of the rods. The rods located in the cusps, the thickest part of enamel are longer than those at cervical areas of the teeth. The diameter of the rods increases from the dentino-enamel junction towards the surface of the enamel at a ratio of about 1:2, the average diameter being 4 μm .

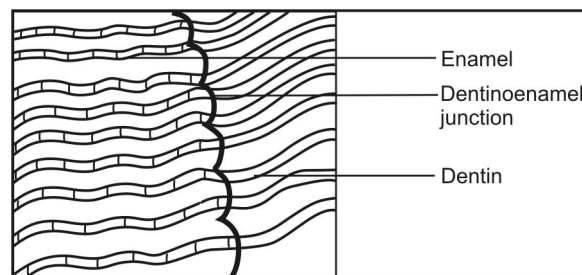


Fig. 5.1: Enamel rods. Under light microscope (Longitudinal section)

In cross section under light microscope, the rods appear hexagonal. They may resemble fish scale or keyhole. Indeed three shapes are commonly seen (Fig. 5.2).

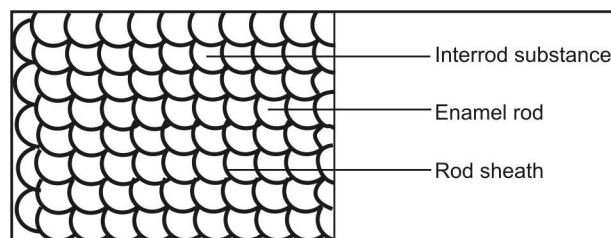


Fig. 5.2: Enamel rods in cross-section

Pattern-1- Prisms appear completely circular, found near dentino-enamel junction

Pattern-2- Prisms are arranged in longitudinal rows.

Pattern-3- Prisms are arranged in rows but are staggered to give the keyhole shape.

Under Electron Microscope

Enamel rod is shaped somewhat like a cylinder and measures about 5 μm in breadth and 9 μm in length. The rods on cross section look like keyholes (Fig.5.3). The rounded portion of each rod lies between the tail of two adjacent rods. Such interlocking arrangement provides enamel

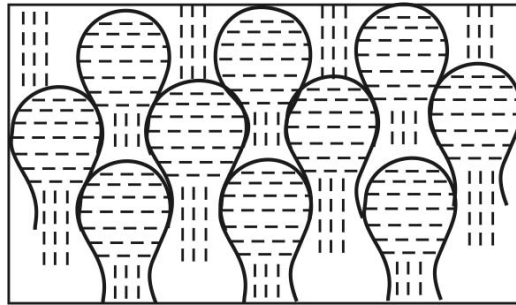


Fig. 5.3: Keyhole appearance of rods

with additional strength and stability. The rod is so oriented that rounded portion points towards occlusal direction and the tail end is oriented towards cervical region.

Each enamel rod is tightly packed with crystallites which vary in shape and size. The mature crystals are ribbon like or hexagonal having an average size of $1,600 \text{ \AA}$ (length) $\times$ $300 \text{ \AA}$ (thickness) $\times$ $900 \text{ \AA}$ (width) (1 nanometer = 10 amstrong unit). The crystals are arranged parallel to the long axes of the rods in round part and deviate about 65° in tail part of the rod (Fig. 5.4).

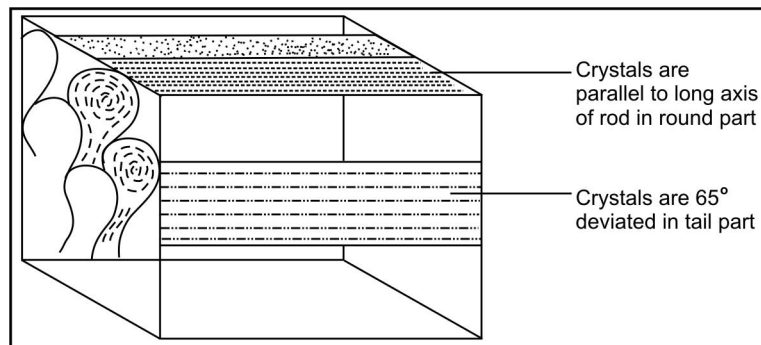


Fig. 5.4: Arrangement of crystals in enamel rod

The organic matrix forms an envelop surrounding each apatite crystal. The surfaces of rods are visible because of abrupt changes in crystal orientation from one rod to another. For this reason the crystals are not tightly packed and there may be more space for organic matrix at these surfaces. This accounts for the rod sheath visible in the light microscope.

Striations—Each enamel rod is built up of segments separated by darklines or transverse striations at $4 \mu\text{m}$ interval.

The reasons for the striations—

1. Enamel matrix is formed in rhythmic fashion and the cross striations are the boundaries of daily matrix deposition.
2. They are the areas of disturbed calcification.
3. They are optical effect due to crystalline orientation.
4. A tertiary curvature or undulation with a periodicity of $4 \mu\text{m}$.

Direction of rod—

The enamel rods are aligned in planes best suited to withstand the masticatory forces. So there are variations in rod orientation in different areas.

Usually rods are oriented at right angles to the dentin surface as well as they end perpendicular to tooth surface. But they follow a wavy course in between.

In deciduous teeth, the rods are perpendicular to the dentino-enamel junction. In cervical and central parts of the crown the rods are horizontal. Near the incisal edge or tip of the cusps they change gradually to an increasingly oblique direction until they are almost vertical (Fig. 5.5A).

In permanent teeth, the arrangement of the rods is similar in the occlusal two-thirds of the crown. In the cervical region, the rods deviate from the horizontal in an apical direction and at acute angle with the dentino-enamel junction (Fig. 5.5B).

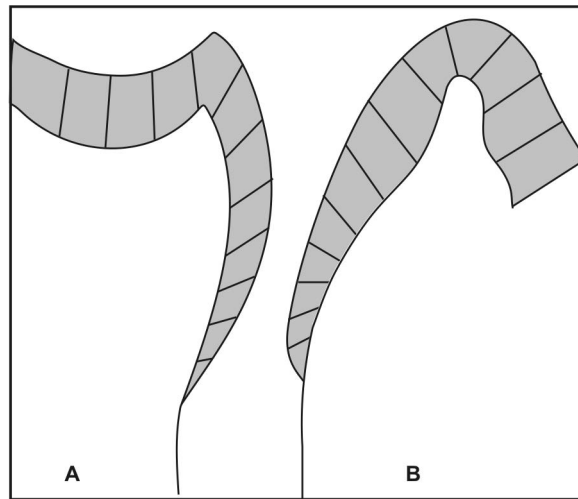


Fig. 5.5: **A.** Direction of rods in deciduous tooth, **B.** Direction of rods in permanent tooth

The enamel rods are divergent at the cuspal eminences while they are convergent in pits and fissure areas (Fig. 5.6).

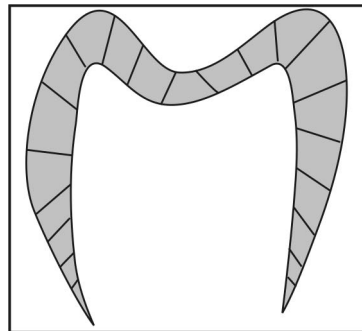


Fig. 5.6: Enamel rods in cuspal eminence and in pits and fissure areas

Groups of rods after leaving dentino-enamel junction curve gently to the right (dextroflexion) and then pursue a straight course for a distance and again curve gently to the left (sinistroflexion), forming an arc (Fig. 5.7).

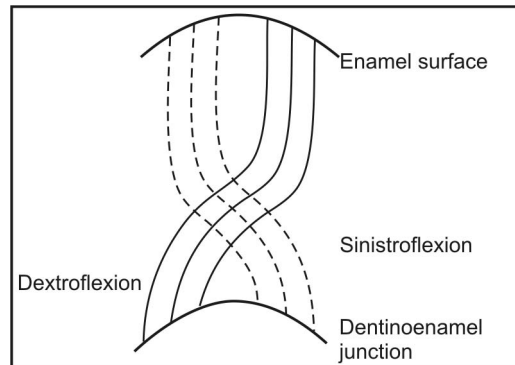


Fig. 5.7: Curvature of enamel rod

If the middle part of the crown is divided into thin horizontal discs, the enamel rods bend toward the right in one disc and then bend toward the left in the adjacent disc (Fig. 5.8). This alternating clockwise and counter-clockwise deviation of the rods can be observed at all levels of the crown if the discs are cut in the planes of rod direction.

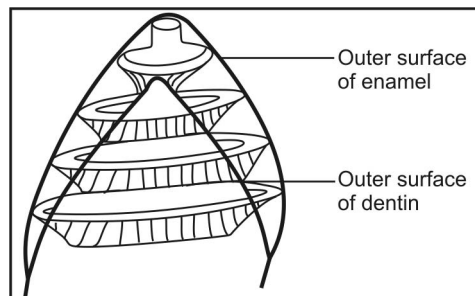


Fig. 5.8: Alternate deviation of enamel rod

Gnarled enamel—If the section of the enamel, cut in an oblique plane is examined, under the microscope, the enamel rods appear twisted around each other in the region of cusps and incisal edge near dentin. The alternate right and left deviation of the rods becomes more complicated in an oblique plane. The bundles of rods appear to intertwine more irregularly. This optical appearance of the enamel is called gnarled enamel (Fig. 5.9). This is associated with an increased strength of the enamel.

Rod sheath—Under light microscope rod sheath appears distinct thin layer peripheral to the rods.

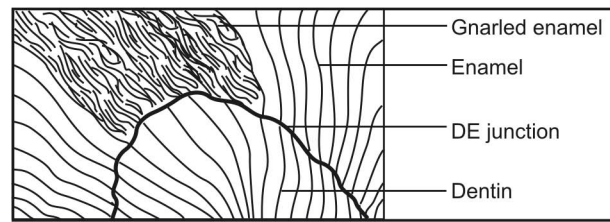


Fig. 5.9: Gnarled enamel

It has a different refractive index.

It stains darker and is more acid resistant than the rods.

It is less calcified and contains more organic substance.

Under electron microscope—According to the electron microscope, the rod sheath is not a discrete structural entity but an organically rich interrod space devoid of apatite crystals.

Interrod substance—The light microscope reveals that the rods are cemented together by interrod substance which has slightly higher refractive index than the rods.

Electron microscopic studies reveal that the enamel prism has a keyhole or fish scale shape. The so called interrod cement substance is an extension or the tail of the adjacent rod. The crystallites at this region have a different orientation than the rounded part which gives optical illusion of a separate cement substance. It contains more organic substance.

Incremental lines of Retzius—The incremental lines of Retzius (Fig. 5.10) are a series of irregularly spaced concentric brown lines seen running obliquely across the enamel rods, when a longitudinal ground section of a tooth is examined under the microscope by transmitted light.

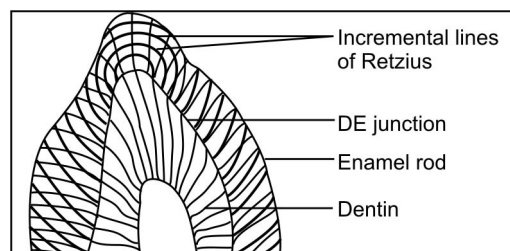


Fig. 5.10: Incremental lines of Retzius

In cuspal or incisal region, they form concentric arcs and terminate at dentino-enamel junction. Near the middle third and cervical region, these parallel lines fan out towards the enamel surface and do not complete the arc.

As the lines of Retzius proceed towards enamel surface, some reach upto enamel and some are falling short of enamel surface. As a result of this there are transverse, wave like grooves present on the surface of the tooth as external manifestations of striae of Retzius. They are

continuous around a tooth, lie parallel to each other and to the cementoenamel junction. They are known as Perikymata (Fig. 5.11). There are around 30 Perikymata per mm in the region of the cementoenamel junction and 10 per mm near occlusal or incisal edge of a surface.

In transverse section, the lines of Retzius, encircle the enamel in the same manner as the annual growth rings of the tree.

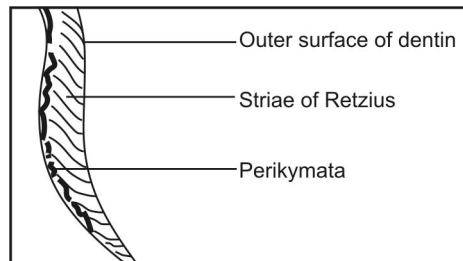


Fig. 5.11: Perikymata

Significance of Lines of Retzius—(Different Views)

1. They signify the incremental pattern of enamel deposition. After 16 μm interval there is a rest period of deposition which is illustrated as Striae of Retzius. They are rich in organic content.
2. Incremental lines have been attributed to periodic bending of the enamel rods.
3. Variation in basic organic structure.
4. Physiologic calcification rhythm.
5. It is a secondary curvature of prism with a periodicity of 16 μm to 100 μm .

Incremental lines are accentuated due to metabolic disturbances, infections (conditions disturbing amelogenesis) causing the rest periods to be the unduly prolonged.

Neonatal line—The deposition of prenatal and postnatal enamel is demarcated by an accentuated line of Retzius, the neonatal line (Fig. 5.12). The disturbance of birth like abrupt change in the environment and nutrition of the newborn infant result in formation of neonatal line. Since these lines are seen in all enamel forming at the time of birth, they are found in all the deciduous teeth and in the larger cusps of the permanent first molars.

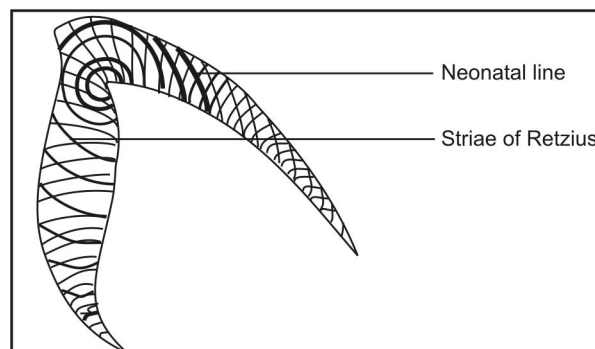


Fig. 5.12: Neonatal line

The prenatal enamel is usually better developed than the postnatal enamel as the fetus develops in a well protected environment with an adequate supply of all the essential materials, even at the expense of the mother.

Because of the undisturbed and even development of the enamel prior to birth, Perikymata are absent in the occlusal parts of the deciduous teeth, whereas they are present in the postnatal cervical parts.

Hunter-Schreger bands—When a longitudinal ground section of tooth is seen in oblique reflected light (light will fall directly on object) a series of alternating dark and light bands are seen in enamel and they are known as Hunter-Schreger bands (Fig.5.13).

They start at the dentino-enamel junction and run perpendicular to the stria of Retzius. These bands are more prominent near dentino-enamel junction and become indistinguishable towards periphery. The dark bands are referred to as Diazones and the light bands are called Parazones.

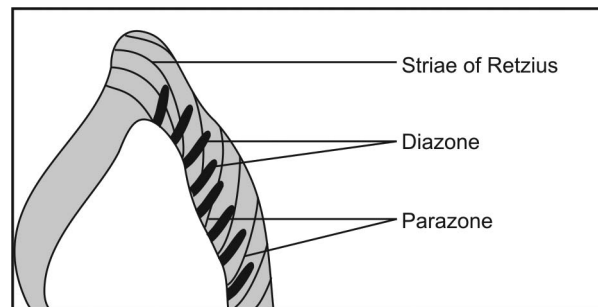


Fig. 5.13: Hunter-Schreger bands

Significance of Hunter-Schreger Bands—(Different Views)

1. It is an optical phenomenon. The change in direction of rods either absorb or reflect light giving rise to dark and light bands.
2. There are variations in calcification of the enamel that coincide with the distribution of the bands of Hunter-Schreger.
3. They are composed of alternate zones having a slightly different permeability and a different content of organic material.
4. It is a primary curvature of prism at a periodicity of about 1,000 μm .

Enamel tufts—In transverse ground section, tasseled or unbraided projections are seen extending from dentino-enamel junction into the enamel to about one-fifth to one-third of its thickness. They are known as enamel tufts as they look like a tuft of grass projecting into enamel (Fig. 5.14). The tuft is a narrow, ribbon like structure, the inner end of which projects into dentin. They follow the direction of enamel rods. It is controversial whether the enamel tufts are composed of rods, rod sheaths or interrod substance. They are hypocalcified structures rich in organic matter and are more permeable. According to one school of thought, when a substance changes from the liquid to the solid state, contractions occur. In enamel, hydroxyapatite changes from the ionic (liquid) state in the ameloblast secretions to the solid state in the enamel crystallites. With the change of state, contractions will be expected and it is possible that these contractions could lead to widening of prism sheaths which correspond with the enamel tuft.

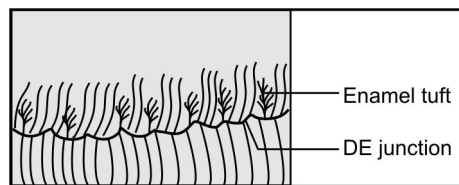


Fig. 5.14: Enamel tufts

Enamel spindles—The odontoblastic processes of dentin may cross the dentino-enamel junction and project into the enamel. They are thickened at their end and are termed enamel spindle (Fig. 5.15).

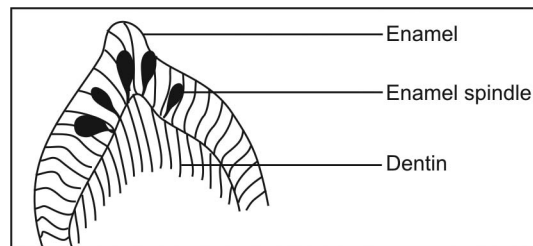


Fig. 5.15: Enamel spindles

They are believed to be formed during formative period of enamel when they insinuate themselves between ameloblasts.

They project at right angles to dentino-enamel junction and correspond to the original direction of the ameloblasts. Since the enamel rods are formed at an angle to the axis of the ameloblasts, the direction of spindles and rods are divergent.

They make the area hypersensitive to pain.

In ground sections of dried teeth, the organic content of the spindles disintegrates and is replaced by air, and the spaces appear dark in transmitted light.

Enamel lamellae—Enamel lamellae (Fig. 5.16) are thin, leaf like structures that extend from the enamel surface toward the dentinoenamel junction. They may extend to, and sometimes penetrate into the dentin. They consist of organic material and little mineral.

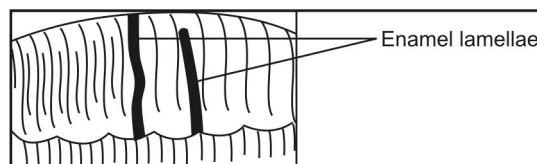


Fig. 5.16: Enamel lamellae

They may be formed before or after eruption. They may develop in planes of tension. Where rods cross such a plane, a short segment of the rod may not fully calcify.

The enamel lamellae are hypomineralized areas containing cellular debris and stain readily with organic dyes. Enamel lamellae are generally seen in cervical region and below pits and fissures in posterior teeth.

Enamel Lamellae may be of Three Types

Type A—Lamellae composed of poorly calcified rod segments.

Type B—Lamellae consisting of degenerated cells.

Type C—Lamellae arising in erupted teeth where the cracks are filled with organic matter, presumably originating from saliva. This is the most common type of lamella.

Type A lamellae are restricted to the enamel, those of types B and C may reach into dentin.

Enamel lamellae represent a defect on the enamel surface and may form a pathway for bacteria and initiation of caries.

[In ground section, enamel lamellae may be confused with cracks caused by grinding of specimen. Careful decalcification of ground sections of enamel makes possible the distinction between cracks and enamel lamellae].

Dentinoenamel junction—The region of the tooth where dentin meets the enamel is dentinoenamel junction.

In a ground section, the dentin at the dentinoenamel junction is pitted. The rounded projections of the enamel are fitted into the pits of dentin. As a result, the junction can be easily seen as a series of scallops. (Fig. 5.17). and convexity of the scallops are directed towards dentin. This causes a firm bondage between these two structures.

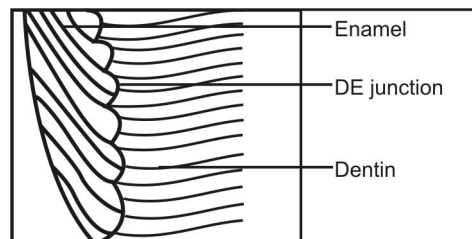


Fig. 5.17: Dentinoenamel junction

In demineralized section, where the enamel has been removed, the scalloped nature of the junction can be clearly seen.

The electron microscope reveals that the crystals of dentin and enamel intermix.

The scanning electron microscope reveals the junction to be a series of ridges rather than spikes, which arrangement probably increases the adherence between dentin and enamel. The ridging is most pronounced in coronal dentin, where occlusal stresses are the greatest. The shape and nature of the junction prevent shearing of the enamel during function.

Cementoenamel junction—It is the region of the tooth where enamel meets the cementum at the cervical line. Three possible variations may exist at the cementoenamel junction. (Fig. 5.18).

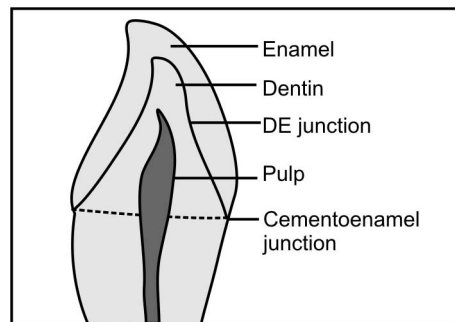


Fig. 5.18: Cementoenamel junction

1. The cervical enamel is covered by cementum for a short distance (Fig.5.19A). It occurs in 60 % of the teeth. This occurs when the enamel epithelium degenerates at its cervical termination, permitting connective tissue to come in direct contact with enamel surface.
2. In approximately 30% of all teeth, cementum meets the cervical end of enamel in a relatively sharp line (Fig.5.19B).
3. In about 10% of the teeth, enamel and cementum do not meet (Fig. 5.19C). This occurs when enamel epithelium in the cervical portion of the root is delayed in its separation from dentin. In such case there is no cementoenamel junction. Instead, a zone of the root is devoid of cementum and for the time being covered by reduced enamel epithelium.

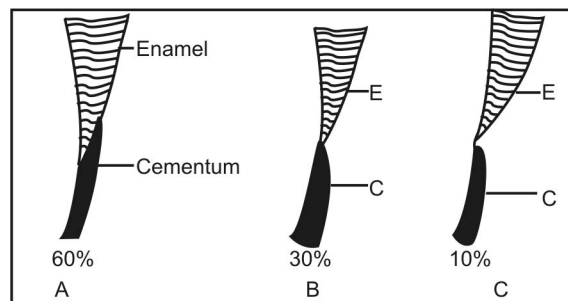


Fig. 5.19A to C: Variations of cementoenamel junction

A. Enamel covered by cementum; **B.** Enamel meets cementum; **C.** Enamel and cementum do not meet

Surface structures—A relatively structureless layer of enamel, approximately 30 μm thick has been described in 70 % of permanent teeth and all deciduous teeth. This enamel is mostly found in the cervical region. This part is heavily mineralized than the bulk of the enamel beneath it.

Enamel cuticle—The crown of a newly erupted tooth is covered by a delicate membrane known as Primary enamel cuticle. It is the last secretory product of ameloblast after the enamel is laid down.

The primary enamel cuticle and reduced enamel epithelium (formed by condensation of outer enamel epithelium, inner enamel epithelium and stratum intermedium) combinedly is known as Nasmyth's membrane.

Under the electron microscope the primary enamel cuticle is 200 nm thick and structurally it is atypical basal lamina found beneath most epithelia. It is organically connected to both enamel matrix and ameloblast.

Like the basement membrane, the cuticle also perhaps control the ionic character of enamel rods by controlling selection and rate of ionic or molecular exchange. This layer is more resistant to acids and alkalies than the enamel.

Mastication and brushing wear away the enamel cuticle after eruption.

Secondary cuticle is the acellular keratinized layer produced by the reduced enamel epithelium after tooth eruption. It covers not only enamel, but also a part of the cementum. It is about 10 µm in thickness.

Pellicle—Enamel is covered by pellicle, the salivary glycoprotein, immediately after eruption. The pellicle reforms within hours after the enamel surface is mechanically cleaned.

Plaque—Within a day or two after the pellicle has formed, it becomes colonized by microorganisms to form bacterial plaque.

Age Changes of Enamel

1. Attrition or wear of the occlusal surfaces or proximal contact points as a result of mastication leads to loss of vertical dimension of crown and flattening of the proximal contour.
2. Total amount of organic matrix increases.
3. Superficial enamel layer becomes rich in nitrogen and fluorine due to continuous uptake and becomes resistant to decay.
4. Permeability to fluid is reduced due to age change process.

Clinical Consideration

1. Enamel can not be repaired in case of damage in attrition due to mastication, abrasion due to abnormal brushing and erosion due to chemicals as ameloblasts undergo degeneration after formation of enamel.
2. Presence of pits and fissures and enamel lamellae are the potential locations for the initiation and propagation of dental caries.
3. Incorporation of fluorine in apatite crystals of enamel by topical application of sodium or stannous fluoride, use of fluoride containing dentifrice and adjustment of fluoride level in communal water supply to 1 part per million forms fluorapatite which makes the tooth resistant against caries.
4. Direction of rods at cervical region are different in deciduous and permanent teeth. The course of enamel rods is of importance in cavity preparation.

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6

Dentin

The dentin is the mineralized tissue forming the main bulk of the tooth. In the coronal part of the tooth, it is covered by the enamel and in the radicular portion by the cementum.

Physical Characteristics

1. *Color*—The color varies from light yellow in deciduous teeth to yellow in permanent dentition. The color becomes darker with age. As the enamel is semi-translucent, dentin gives its color to the crown of the tooth.
2. *Hardness*—It is softer than enamel but harder than bone and cementum. The hardness varies in different areas of dentin. The highest microhardness is seen in areas about 450 μm from dentinoenamel junction with an average KHN-70 (knoop hardness number: enamel-300 KHN). The lowest value (20 KHN) is found in about 100 μm from the dentinoenamel junction. Hardness increases with age.
3. *Permeability*—It is highly permeable because of dentinal tubules. Permeability decreases with advancing age.
4. *Tensile strength and compressibility*—It is highly elastic. This property is essential for the support of non resilient enamel. Dentin has greater compressive and tensile strengths than enamel.
5. It is semitransparent and more so in deciduous teeth.
6. *Radio density*—It is less mineralized than enamel and is therefore less radiopaque than enamel.
7. It shows positive birefringence under polarized light.
8. *Specific gravity*—The specific gravity of dentin is approximately 2.1.

Chemical Composition

	<i>By weight</i>	<i>By volume</i>
Inorganic	70%	47%
Organic	20%	32%
Water	10%	21%

The inorganic component consists of hydroxyapatite crystals, $3\text{Ca}_3(\text{PO}_4)_2 \cdot \text{Ca}(\text{OH})_2$. The crystals are plate shaped and much smaller than the hydroxyapatite crystals in enamel. Dentin also contains small amounts of fluoride, phosphates, carbonates and sulfates.

The organic substance consists of collagenous fibril (Type 1 collagen, 90% of matrix) and a ground substance of mucopolysaccharides (proteoglycans and glycosaminoglycans), phosphoprotein and 1.7 % lipid.

Structure of Dentin

The dentin is composed of the following—

1. The dentinal tubules containing the protoplasmic processes of odontoblasts,
2. Dentinal matrix.

The cell bodies of the odontoblasts are arranged in a layer on the pulpal surface of the dentin and only their cytoplasmic processes are included in the tubules in the mineralized matrix. (Fig. 6.1). Each cell gives rise to one process, which traverses the predentin and calcified dentin within one tubule and terminates in a branching network at the junction with enamel and cementum. Tubules are found throughout normal dentin and therefore characteristic of it.

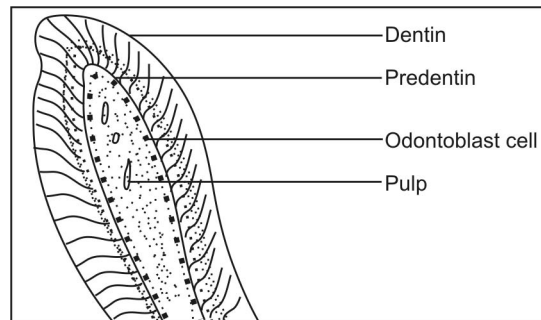


Fig. 6.1: Odontoblast cell

Dentinal Tubules

The dentinal tubules follow a S-shaped curvature which is more pronounced in crown and less in root. Starting at the right angle from the pulpal surface, the first convexity is directed towards the apex of the tooth (Fig. 6.2). These tubules end perpendicular to the dentinoenamel and dentinocemental junctions. Near the root tip and along the incisal edges and cusps, the tubules are almost straight. Over their entire lengths, the tubules exhibit minute, relatively regular secondary curvatures that are sinusoidal in shape.

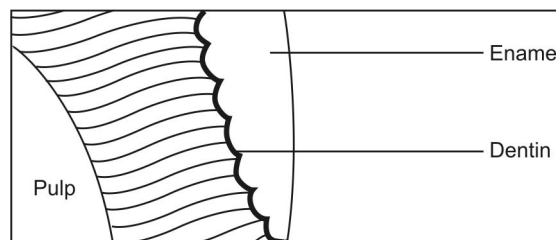


Fig. 6.2: S-shaped curvature of dentinal tubules

The ratio between the outer and inner surfaces of dentin is about 5:1. So the tubules are wide apart in periphery and more closely packed near the pulp.

The tubules are larger in diameter near the pulpal cavity (3-4 μm) and smaller at their outer ends (1 μm).

The ratio between the number of tubules per unit area on the pulpal and outer surfaces of the dentin is about 4:1. Near the pulpal surface of the dentin the number of tubules per square millimeter varies between 50,000 and 90,000. There are more tubules per unit area in the crown than in the root.

The dentinal tubules have lateral branches throughout dentin (Fig. 6.3). They are termed canaliculi or microtubules. These canaliculi are 1 μm or less in diameter and originate more or less at right angle to the main tubule. Some of them enter adjacent or distant tubules while others end in the intertubular dentin.

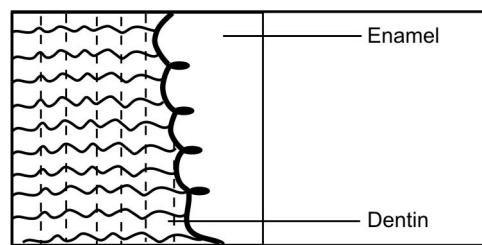


Fig. 6.3: Secondary curves and lateral branches of dentinal tubules

A few dentinal tubules extend throughout the dentinoenamel junction into the enamel for several millimeters. These are termed enamel spindles.

Peritubular (Intratubular) Dentin

The hypermineralized dentin surrounding the dentinal tubules is termed peritubular dentin. (Fig.6.4). It is 9 % more mineralized than intertubular dentin.

It is roughly 44 nm wide near the pulp end, 750 nm wide near the dentinoenamel junction, and sharply demarcated from the intertubular dentin.

By its growth, it constricts the dentinal tubule to a diameter of 1 μm near dentinoenamel junction.

After decalcification the odontoblast process appears to be surrounded by an empty space due to demineralization of hypercalcified area.

According to some investigators, the calcified tubule wall has an inner organic lining termed the lamina limitans which is rich in glucosaminoglycan.

[Anatomically, however, the term peritubular dentin is incorrect because this dentin forms within the dentinal tubule (not around it), narrowing the tubular lumen. So it is more accurately intratubular rather than peritubular dentin].

Intertubular Dentin

It is located between the zones of peritubular dentin (Fig. 6.4) and forms the main bulk of dentin. Organic matrix is half of its volume and collagen fibers are oriented around the dentinal tubules. The fibrils range from 0.5 to 0.2 μm in diameter and exhibit crossbanding at 64 nm (640 $\text{\AA}$) intervals, which is typical for collagen. Hydroxyapatite crystals, which average

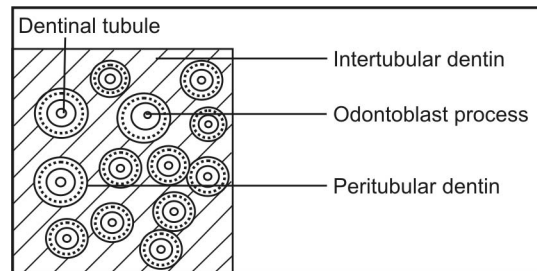


Fig. 6.4: Peritubular and intertubular dentin

0.1 μm in length, are formed along the fibers with their long axes oriented parallel to collagen fibers.

Predentin

The predentin is the unmineralized matrix of dentin, adjacent to the pulp tissue and is 2-6 μm wide, depending on activity of the odontoblast (Fig.6.5). It consists principally of collagen, glycoproteins and proteoglycans. This layer of predentin is always present as deposition of mineral lags behind the formation of organic matrix of dentin. As the collagen fibers undergo mineralization at the predentin-dentin front, the predentin then becomes dentin and a new layer of predentin forms circumpulpally. The rate of deposition of predentin diminishes with advancing age.

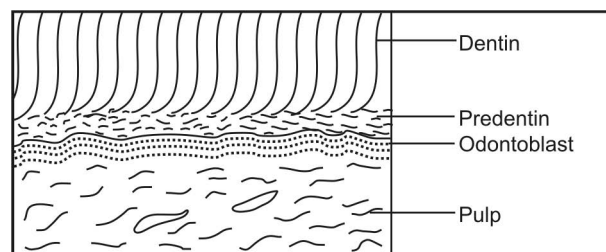


Fig. 6.5: Predentin

Odontoblast Process

The odontoblast processes are the cytoplasmic extensions of the odontoblasts. The odontoblasts reside in the peripheral pulp at the pulp-predentin border and their processes extend into the dentinal tubules (Fig. 6.6).

The processes are largest in diameter near pulp (3-4 μm) and taper to approximately 1 μm further into dentin. They are closely packed near pulp (around 75,000/sq.mm.) and spread widely at periphery (30,000/sq.mm.) These processes give off lateral branches that radiate diagonally towards outer dentinal surface and extend laterally into adjacent tubule. The processes end in several terminal branches that extend up to dentinoenamel and dentinocemental junction. A few tubules may extend beyond the dentinoenamel junction into the enamel and are known as enamel spindles.

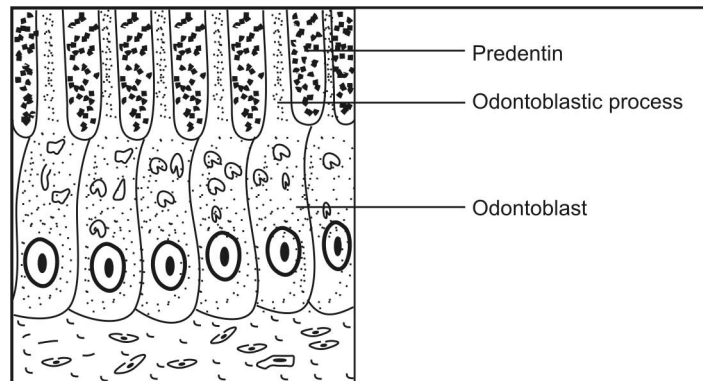


Fig. 6.6: Odontoblast process

The odontoblastic process (Fig. 6.7) lies within a cell membrane. The process is composed of microtubules of 20 μm in diameter and small filaments 5 to 7.5 μm in diameter. Occasionally mitochondria, lysosomes, microvesicles, and coated vesicles that may open to the extracellular space are also seen.

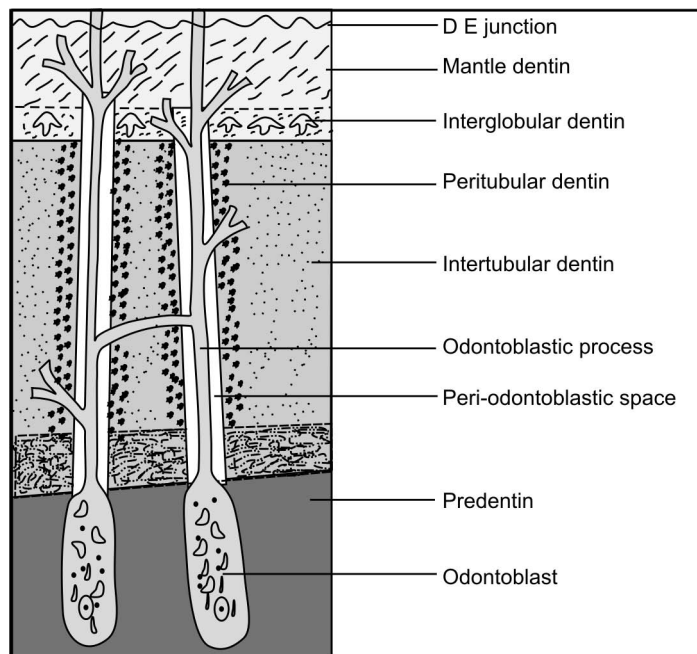


Fig. 6.7: Odontoblast and its process in the dentinal tubule

[Different opinion of investigators whether the odontoblast processes extend through the thickness of mature human dentin—

- a. Transmission electron microscopy—The dentinal tubules contain odontoblast process upto 200 to 300 μm from the pulp.

- b. Scanning electron microscopy—shows presence of odontoblastic process at dentino-enamel junction. Some investigators believe that it is not the living process of the odontoblast but the organic lining membrane of the tubule (lamina limitans).
- c. Cryofractured human teeth—reveal the odontoblast process to extend to the dentino-enamel junction.
- d. Immunofluorescent technique—reveals tubulin (as intracellular protein of microtubules) throughout the thickness of dentin.

From different opinions, it is appropriate to consider that some odontoblast processes traverse the thickness of dentin. In other areas a shortened process may be characteristic in tubules that are narrow or obliterated by mineral deposit.

Different Forms of Dentin

Dentin formation is a continuous process and three different types of dentin are recognized.

- A. *Primary dentin*—It is the dentin formed from initial phase upto the completion of root.
 - a. *Mantle dentin*—is the first-formed dentin in the crown underlying the dentino-enamel junction. It is thus the outer or most peripheral part of the primary dentin and is about 20 μm thick.

The collagen fibers of mantle dentin are perpendicular to the enamel-dentin junction and it is hypomineralized compared to circumpulpal dentin. The dentinal tubule in mantle dentin branch more profusely than those in circumpulpal dentin.

- b. *Circumpulpal dentin*—forms the remaining primary dentin or bulk of the tooth. It represents all of the dentin formed prior to root completion.

The collagen fibers are much smaller in diameter (0.05 μm) and are more closely packed together. They are parallel to the dentinoenamel junction. The circumpulpal dentin may contain slightly more mineral than mantle dentin.

- B. *Secondary dentin (physiologic secondary dentin)*—It is a narrow band of dentin bordering the pulp and representing that dentin formed after root completion. This dentin contains fewer tubules than primary dentin. There is usually a bend in the tubules where primary and secondary dentin interface (Fig. 6.8).
- C. *Tertiary dentin (reactive, reparative or irregular secondary dentin)*—It is produced in reaction to various stimuli, such as attrition, caries or a restorative dental procedure. It is produced only by cells directly affected by the stimulus. The quality and quantity of tertiary dentin produced are related to the cellular response initiated, which depends on the intensity and duration of the stimulus. The dentin contains regularly or irregularly arranged tubules which are sparse in number. The cells forming tertiary dentin either line its surface or are included in the dentin and in the later case, the dentin is referred to as osteodentin.

Incremental lines of Von Ebner—The incremental lines of Von Ebner or imbrication lines (Fig. 6.9) appear as fine lines or striations in dentin. They reflect the daily rhythmic, recurrent deposition of dentin matrix and period of rest between daily increments. The distance between lines varies from 4 to 8 μm in the crown and much less in the root. The daily increment decreases after a tooth reaches functional occlusion. The course of the lines indicates the growth pattern of the dentin. These fine lines run at right angles to the dentinal tubules.

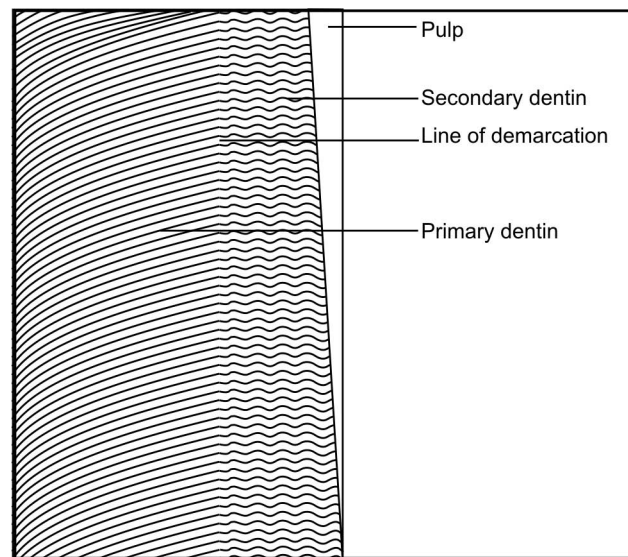


Fig. 6.8: Secondary dentin

Some incremental lines are accentuated because of disturbances in the matrix and mineralization process. These are hypocalcified bands and are known as Contour lines of Owen.

Neonatal line—This is an accentuated, hypocalcified contour line separating the prenatal and postnatal dentin (Fig. 6.9). The line reflects the abrupt change in environment that occurs at birth. There is interruption of growth due to metabolic adjustment. The dentin matrix formed prior to birth is usually of better quality than that formed after birth. These lines are seen in the deciduous teeth and permanent first molar.

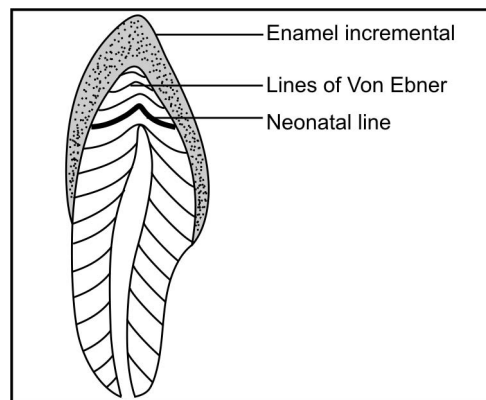


Fig. 6.9: Incremental lines of Von Ebner and neonatal line

Interglobular dentin—Sometimes mineralization of dentin begins in small globular areas that fail to fuse into a homogenous mass. This results in zones of hypomineralization between the

globules. These zones are known as interglobular dentin (Fig. 6.10). These are seen in the crown of the teeth in circumpulpal dentin just below the mantle dentin and it follows the incremental pattern. The dentinal tubules pass uninterrupted through interglobular dentin. Thus it reveals a defect of mineralization and not matrix formation.

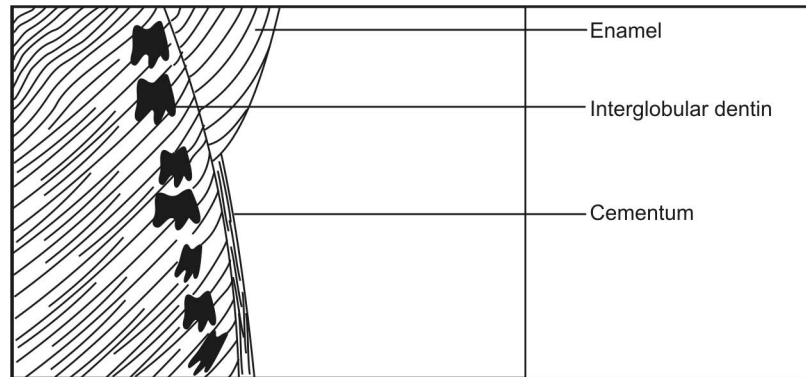


Fig. 6.10: Interglobular dentin

Granular layer of Tomes—When dry ground sections of the root dentin are examined under the microscope in transmitted light, a thin granular layer is visible in dentin adjacent to cemento-dentinal junction. This layer is known as Tomes' granular layer (Fig.6.11).

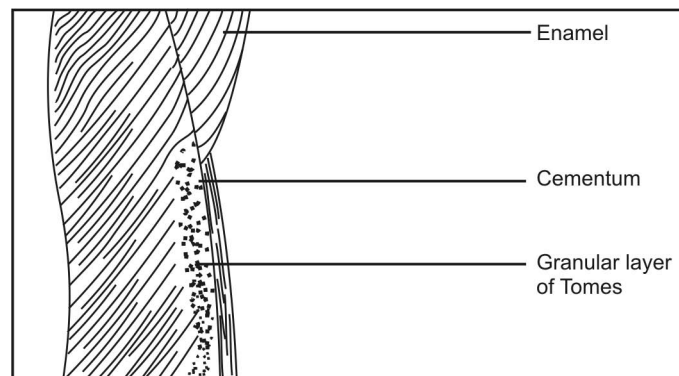


Fig. 6.11: Granular layer of Tomes and dentinocemental junction

This zone increases slightly in amount from the cemento-enamel junction to the root apex. It is caused by a coalescing and looping of the terminal portions of the dentinal tubules.

Dentinocemental junction—This is a thin smooth boundary line between dentin and cementum in permanent tooth and scalloped in deciduous tooth. The attachment is firm in both sets of dentition. It is peripheral to Tomes' granular layer. It is debatable whether this layer is a form of dentin or a distinct tissue forming part of the tooth's attachment apparatus and cementing cementum to dentin (Fig. 6.11).

Innervation of dentin—Dentin is a highly sensitive tissue. The anatomic basis and mechanism for this sensitivity is highly controversial.

The myelinated nerve fibers of pulp lose their myelin sheath in subodontoblastic layer and traverse upto odontoblast layer. Some of the fibers end in predentin and inner dentin upto 100 to 150 μm from the pulp. Most of these small vesiculated endings are located in tubules in coronal part of tooth, specially in the pulp horn. The nerves and their terminals are found in close association with the odontoblast process within the tubule. The primary afferent somatosensory nerves of the dentin and pulp project to the main sensory nucleus of the midbrain.

Theories of Pain Transmission through Dentin

There are three basic theories of pain conduction through dentin—

1. *Direct neural stimulation*—The stimuli in some manner as yet unknown, reach the nerve ending of inner dentin. The theory is not widely accepted.
2. *Hydrodynamic theory*—Various stimuli such as heat, cold, airblast desiccation, or mechanical pressure affect fluid movement in the dentinal tubules. This fluid movement, either inward or outward, stimulates the pain mechanism in the tubules by mechanical disturbance of the nerves closely associated with the odontoblast and its process. This is the most popular theory.
3. *Transduction theory*—According to this theory the odontoblast process is the primary structure excited by the stimulus and that the impulse is transmitted to the nerve endings in the inner dentin. This is also not well accepted theory as there is no neurotransmitter vesicles in the odontoblast process to facilitate the synapse.

Age and Functional Changes

Vitality of dentin—Dentin is a vital tissue and it reacts to physiologic stimuli. Though the dentin is laid down throughout the life of tooth, after eruption, dentinogenesis slows down. Dentin reacts differently to mechanical, bacterial (dental caries), thermal, chemical and electrical stimulation depending upon the intensity of the stimulus.

Reparative dentin—It is a localized deposit of dentin on the wall of the pulp cavity as a reparative process, when odontoblast cells are damaged due to external stimulation like attrition, abrasion, erosion and dental caries (Fig. 6.12A to D). The majority of odontoblasts degenerate and are replaced by the migration of undifferentiated perivascular cells from deeper region of pulp.

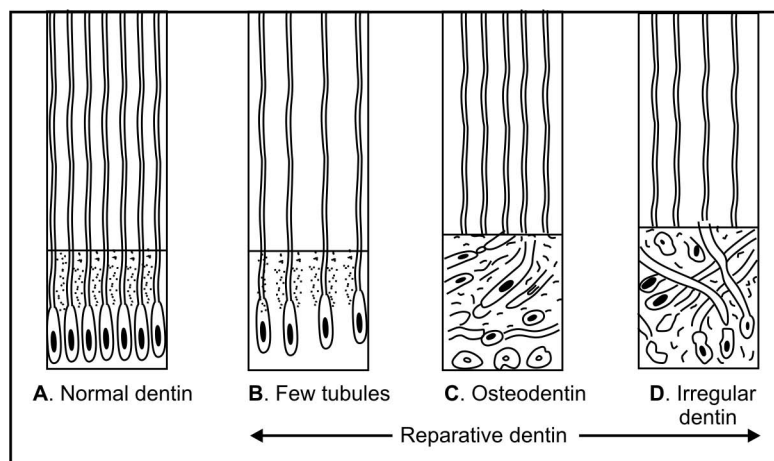


Fig. 6.12: Diagram showing normal and reparative dentin

Both damaged odontoblasts and newly differentiated odontoblasts begin deposition of reparative dentin to seal off the zone of injury.

Reparative dentin is characterized by fewer and more twisted tubules and less mucopolysaccharide than normal dentin. Dentin forming cells are often included in the matrix forming osteodentin. As tubules are sparse and there is irregular, dense calcification, the reparative dentin appears white in transmitted light and dark in reflected light (Fig. 6.13).

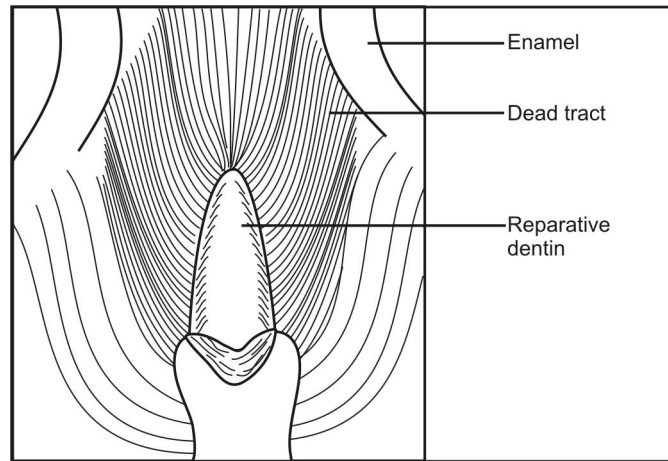


Fig. 6.13: Reparative dentin

Dead tracts—These are groups of dark lines that follow the course of dentinal tubules, visible when ground section of dentin is examined under transmitted light. They appear white under reflected light. (Fig. 6.14A and B). The reasons for the formation of the dead tracts are that the odontoblast cells may die or may be injured due to (1) violent stimuli like— a) bacterial (caries) b) mechanical (wearing down of tooth due to attrition, abrasion, erosion or cavity preparation) c) thermal, chemical, electrical (from improper restoration of tooth) or due to (2) overcrowding of odontoblasts (near the area of narrow pulpal horn).

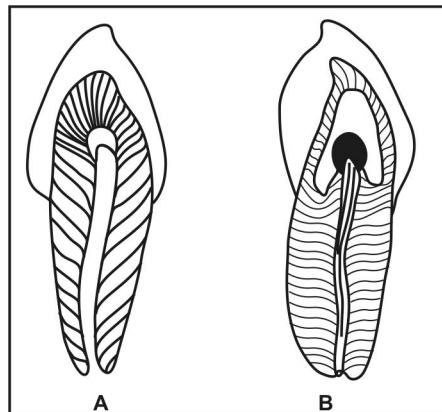


Fig. 6.14: Dead tract

A. Black in transmitted light, B. White in reflected light

As a result there is either degeneration or retraction of odontoblast process and the dentinal tubules are filled with fluid or gaseous substances which appear black in transmitted light and white in reflected light.

The areas of dead tracts demonstrate decreased sensitivity and appear to a greater extent in older teeth.

Sclerotic Dentin—(Transparent Dentin)

It is hypermineralized dentin which appears white or transparent when a ground section of dentin is examined under transmitted light and dark in reflected light (Fig. 6.15).

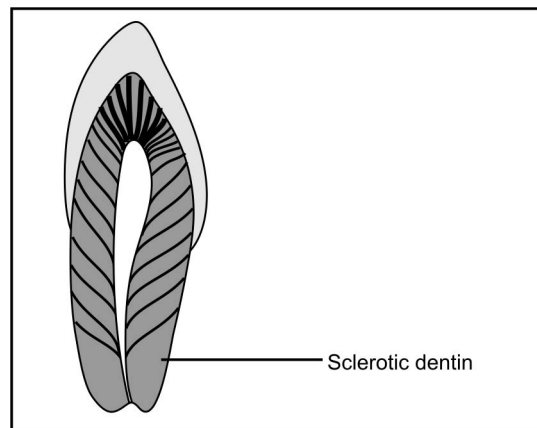


Fig. 6.15: Sclerotic dentin

Instead of forming reparative dentin or dead tracts, external stimulation (Mechanical, Thermal, Chemical, Electrical, Bacterial) may lead to protective changes in the dentin itself. Sometimes external stimulation may lead to the appearance of collagen fibers and apatite crystals in the dentinal tubules. Gradually, the tubule lumen is obliterated with mineral and the refractive index equalizes with adjacent dentin. When this occurs in several tubules in the same area, the dentin assumes a glassy appearance and becomes translucent.

The amount of sclerotic dentin is increased with age and is most common in the apical third of the root and in the crown midway between the dentinoenamel junction and the surface of the pulp.

Because sclerosis reduces the permeability of dentin, it may help to prolong pulp vitality.

Clinical Consideration

1. Exposed dentin surface should be sealed with a nonirritating, insulating substance as exposure of 1 sq. mm. of dentin to noxious stimuli leads to damage of about 30,000 living cells.
2. Tubular configuration of dentin causes rapid penetration and spread of dental caries, pulpitis and toothache.
3. Being elastic, dentin supports the overlying enamel and the base of cavity preparations is always placed in dentin.

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The pulp is a delicate mesenchymal connective tissue that occupies the pulp cavity in the central part of tooth. It is surrounded by dentin on all sides except at the apical foramen and accessory pulp canal openings where it is in communication with periodontal soft tissue. Every person normally has a total of 52 pulp organs, 32 in the permanent and 20 in the primary teeth. The total volumes of all permanent teeth pulp organs is 0.38 cc. and the mean volume of a single adult human pulp is 0.02 cc. Molar pulps are three to four times larger than incisor pulps.

Function

1. *Inductive*—The first role of the pulp anlage is to induce oral epithelial differentiation into dental lamina and enamel organ formation.
The pulp anlage also induces the developing enamel organ to become a particular type of tooth.
2. *Formative*—The main function of pulp is formation of dentin, as odontoblasts, the dentin forming cells are present bordering the pulp tissue.
3. *Nutritive*—It supplies nutrition to the dentin through blood vessels and odontoblastic processes and maintain vitality of tooth.
4. *Sensory*—The sensory nerves in the pulp respond with pain to all stimuli such as heat, cold, pressure, operating cutting procedures and chemical agents. The nerves also initiate reflexes that control circulation in the pulp.
5. *Defensive*—The pulp is an organ with remarkable reparative abilities. It responds to irritation like mechanical, thermal, chemical or bacterial and it protects itself and the vitality of the tooth by producing reparative dentin and mineralizing any affected dentinal tubule.

Anatomy

The pulp cavity is divided into—

1. *Pulp chamber (Coronal pulp)*—In young teeth the shape of pulp chamber is same as the outline of outer surface of dentin. The extension of the pulp chamber into the cusps of tooth are called pulpal horns. The pulp chamber is large at the time of eruption but become smaller with advancing age due to deposition of secondary dentin.
2. *Root canal (Radicular pulp)*—It extends from cervical region of the crown to the root apex. In the anterior teeth the radicular pulps are single and in posterior ones multiple. The

shape of the radicular pulp is tubular. It is continuous with peri-apical connective tissues through apical foramen.

3. *Apical foramen*—The location, shape, size and number of the apical foramen vary. The opening may be bounded by dentin or by cementum.

The average size of the apical foramen of maxillary teeth in adult is 0.4 mm. In mandibular teeth it is slightly smaller, being 0.3 mm in diameter.

4. *Accessory canals*—Accessory canals leading from the radicular pulp laterally through the root dentin to the periodontal tissue may be seen anywhere along the root but are particularly numerous in the apical third of the root. It is formed may be due to premature loss of root sheath cells and subsequent failure of dentin formation in a localized region. Accessory canals may also occur where developing root encounters a blood vessel. If the vessel is located in the area where dentin is forming, the hard tissue may develop around it, making a lateral canal from the radicular pulp.

Table 7.1: Pulp organs of different teeth (Permanent series)

<i>Maxillary teeth</i>	<i>Coronal pulp</i>	<i>Radicular pulp</i>	<i>Volume of pulp</i>
Central incisor	Shovel shaped, 3 short horns.	Triangular in cross section with point of triangle pointing lingually.	0.012 cc
Lateral incisor	Spoon shaped	Round in cross section evenly tapered to apex.	0.011 cc
Canine	Longest pulp, elliptical in cross section	Distally inclined apex.	0.015 cc
First premolar	Large occlusocervical pulp organ	Two smooth funnel-shaped radicular pulp.	0.018 cc
Second premolar	same	one root	0.017 cc
First molar	Roughly rectangular cervical cross section with the greatest dimension buccolingually with mesio-buccal prominence.	Three radicular pulp, lingual is longest	0.068 cc
Second molar	same	same	0.044 cc
Third molar	same	same	0.023 cc
<i>Mandibular teeth</i>			
Central incisor	Smallest pulp organ, long, narrow with a flattened elliptical shape in cross section buccolingually	Single, narrow radicular pulp	0.006 cc
Lateral incisor	Same as central only smaller in all dimensions	same	0.007 cc
Canine	Similar to but shorter than maxillary canine	Radicular pulp begins tapering at midpoint, ending in a distally inclined apex	0.014 cc
First premolar	Similar to mandibular canine but missing lingual pulp horn.	Single radicular pulp	0.015 cc

Contd...

Contd...

Maxillary teeth	Coronal pulp	Radicular pulp	Volume of pulp
Second premolar	Similar to mandibular canine, lingual horn-smaller.	Single and triangular in cross section.	0.015 cc
First molar	Coronal cross-section is rectangular with the mesiodistal dimension greatest. It shows mesiobuccal prominence with highest mesiobuccal horn.	Two radicular pulp, distal being shorter, straighter, singular.mesial-is longer, curved and doubled.	0.053 cc
Second molar	same	same	0.032 cc
Third molar	same	same	0.031 cc.

Development

The tooth pulp is initially called dental papilla. It is designated as pulp only after dentin forms around it.

In the earliest stages of tooth development it is the area of the proliferating future papilla that causes the oral epithelium to invaginate and form the enamel organs. These organs then enlarge to enclose the dental papillae in their central portions.

The dental papilla further controls whether the forming enamel organ is to be an incisor or a molar.

The young dental papilla is highly vascularized, and a well-organized network of vessels appears by the time dentin formation begins.

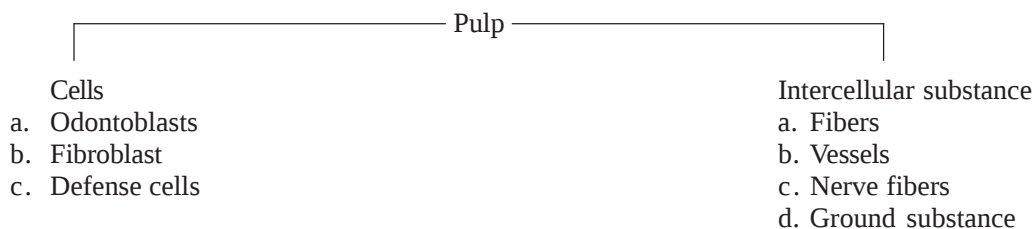
The cells of the dental papilla appear as undifferentiated mesenchymal cells which differentiate into stellate-shaped fibroblasts.

Ameloblasts are differentiated from inner enamel epithelium and the odontoblasts are differentiated from peripheral cells of the dental papilla. As dentinogenesis begins, the dental papilla is designated as pulp organ.

Few large myelinated nerves are found in the pulp until the dentin of the crown is well advanced. At that time nerves reach the odontoblastic zone in the pulp horns. The sympathetic nerves, however, follow the blood vessels as the pulp begins to organize.

Structural Features

The pulp consists of (1) Cells and (2) Inter cellular substance.



From periphery to the center the different zones are—(Fig. 7.1)

1. The odontoblast cell layer.
2. The cell free zone. (Weil's Zone)
3. The cell rich zone.

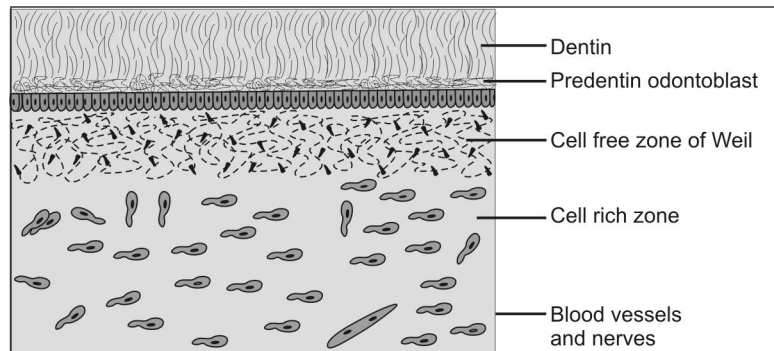


Fig. 7.1: Diagram of pulp

Odontoblast

The odontoblasts are highly differentiated connective tissue cells. They lie in a continuous row near the dentinal end of the pulp and their protoplasmic processes project through the dentinal tubules.

They are tall columnar in the crown (Fig. 7.2), cuboidal in the middle of the root and flat spindle shaped near the apex of tooth. They are approximately 25 to 40 μm in length and 5 to 7 μm in diameter.

The cell contains a large oval nucleus which fills the basal part of the cells. The nuclei are placed at different levels and therefore the cells appear to be stratified. The cells in the odontoblastic row lie very close to each other and the plasma membranes of adjacent cells exhibit junctional complexes.

Immediately adjacent to the nucleus, basally is rough endoplasmic reticulum and the golgi apparatus. Further toward the apex of the cell appears an abundance of rough surfaced endoplasmic reticulum. There is a striking difference in the cytoplasm of the young cell body,

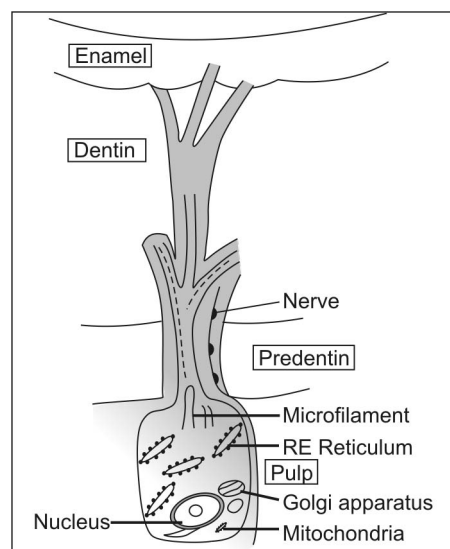


Fig. 7.2: Odontoblast

active in dentinogenesis and the older cell. During the early active phase the golgi apparatus is more prominent, the rough endoplasmic reticulum is more abundant and numerous mitochondria appear throughout the odontoblast.

Near the pulpal-predentin junction the cell cytoplasm is devoid of organelles. The clear terminal part of the cell body and the adjacent intercellular junction is known as the terminal bar apparatus of the odontoblast.

At this zone the cell constricts to a diameter of 3 to 4 μm where the cell process enters the predentin tubule. The process of the cell contains no endoplasmic reticulum except at the early period of active dentinogenesis when it contains occasional mitochondria and a great number of vesicles. There is evidence of protein synthesis along the tubule wall. The main process of odontoblast cell is known as Tomes' Process.

Function—Formation of Dentin

In the crown, just deep to odontoblast layer, a zone is seen which is comparatively devoid of cells. It is known as cell free zone (zone of Weil or Subodontoblastic layer). It contains a network of nerve fibers, the Subodontoblastic plexus or plexus of Raschkow.

In zone of Weil, though cells are very few in number, fibroblasts and mesenchymal cells in this zone may differentiate to odontoblast on demand. Nerves and blood vessels pass through zone of Weil to arrive at odontoblast and predentin. This zone is generally not seen in young teeth and therefore may be an artifact (a defect during tissue processing). Deeper to the cell free zone there is a narrow zone of pulp tissue in which the cells are more numerous than elsewhere in the pulp. This zone has a rich capillary network. This cell rich zone is also present in root but not conspicuous.

Fibroblasts

The fibroblasts are the most numerous cell type in the pulp. They have typical stellate shape and extensive processes are joined by intercellular junctions to the processes of other fibroblasts.

Under light microscope the fibroblast nuclei stain deeply with basic dyes, (Hematoxylin), cytoplasm is lighter stained and appears homogeneous.

Electron microscope reveals abundant rough-surfaced endoplasmic reticulum, mitochondria and other organelles in the fibroblast cytoplasm. This indicates that these cells are active in pulpal collagen production and are seen in young pulp.

In older pulp they appear rounded or spindle shaped with short processes and exhibit fewer intracellular organelles. They are termed fibrocytes.

Functions: (1) synthesis of collagen fiber throughout the pulp matrix during the life of the tooth. (2) capable of ingesting and degrading the same matrix.

Defense Cells

The cells which are important to the defense of the pulp are the histiocytes or macrophage, mast cells, and the plasma cells (Fig. 7.3). In addition, there are cells from blood vascular elements such as the neutrophils, eosinophils, basophils, lymphocytes and monocytes.

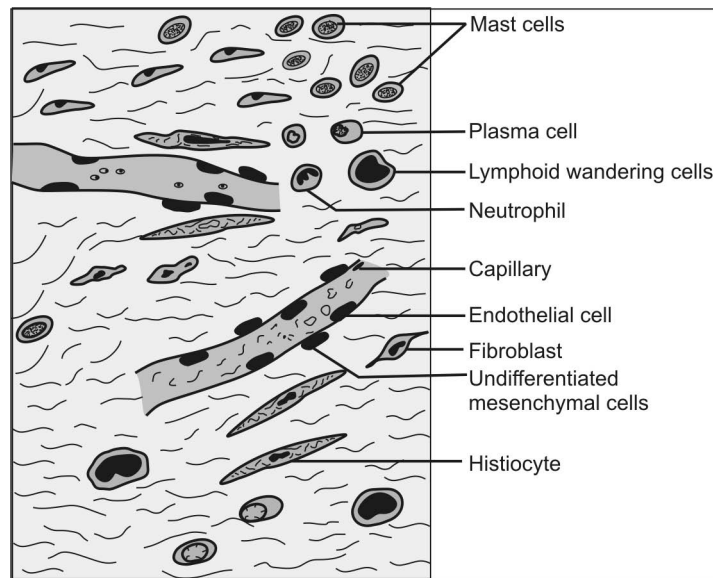


Fig. 7.3: Defense cells of pulp

- a. *Histiocyte*—The histiocyte or macrophage, is an irregularly shaped cell with short blunt processes.

In the light microscope the nucleus is somewhat smaller, more rounded, and darker staining than that of fibroblasts and it exhibits granular cytoplasm. These cells are usually associated with small blood vessels and capillaries.

Ultrastructurally, the macrophage exhibits a rounded outline with short, blunt processes and contain mitochondria, rough surfaced endoplasmic reticulum, free ribosomes and also a moderately dense nucleus. There are aggregates of vesicles, or phagosomes, which contain phagocytized dense irregular bodies.

- b. Lymphocytes and eosinophils are found extravascularly in the normal pulp but during inflammation they increase in number.
- c. Mast cells are seen along the vessels in the inflamed pulp. They have a round nucleus and contain many dark-staining granules in the cytoplasm.
- d. Plasma cells are seen during inflammation of the pulp. With the light microscope the plasma cell nucleus appears small and concentric in the cytoplasm. The chromatin of the nucleus is adherent to the nuclear membrane and gives the cell a cartwheel appearance. The cytoplasm is basophilic with a light stained Golgi zone adjacent to nucleus.

Under electron microscope, the cell have a densely packed, rough surfaced endoplasmic reticulum.

Function— Production of antibodies.

- e. *Lymphoid wandering cells*: They originate in the blood stream and can act as macrophage.

Undifferentiated Mesenchymal Cells

These cells are seen in very young pulp but only a few are seen in the pulps after root completion. They are polyhedral in shape with peripheral processes and contain large oval nuclei. They are found along pulp vessels, in the cell rich zone and scattered throughout central pulp. They are totipotent cell and on demand they may become odontoblast, fibroblast or macrophages.

Intercellular substance

It is a dense, gel like substance, composed of—

- a. Acid mucopolysaccharides.
- b. Protein polysaccharide (glycosaminoglycans and proteoglycans).
- c. Chondroitin A.
- d. Chondroitin B.
- e. Hyaluronic acid
- f. Glycoprotein.

Function

1. It lends support to the cells of the pulp.
2. It serves as a means for transport of nutrients from the blood vessels to the cells.
3. It also serves as a transport of metabolites from cells to the blood vessels.

Fibers

The collagen fibers in pulp exhibit typical cross striation and at 64 nm (640 Amstrong) and range in length from 10 to 100 nm or more. In young pulp fibers ranging in diameter from 10 to 12 nm have been observed. Fibers may appear scattered throughout the coronal or radicular pulp and these are termed diffuse collagen or they may appear in bundles and are termed bundle collagen. Fiber bundles are more prevalent in root canals specially near apical region. After root completion the pulp matures and bundles of collagen fibers increase in number.

Blood Vessels

The pulp organ is highly vascularized. Blood vessels arise from the inferior or superior alveolar artery and also drain by the same veins in both the mandibular and maxillary regions. The pulp vessels communicate with the vessels of periodontium through apical foramen and also through accessory canals.

Small arteries and arterioles enter the apical canal and pursue a direct route to the coronal pulp. Along their course they give off numerous branches in the radicular pulp that pass peripherally to form plexus in the odontogenic region. The capillaries form loops close to odontoblast and form a plexus in subodontoblastic zone. From this plexus, branches pass between the odontoblasts towards predentin and may form a plexus near it.

Pulpal blood flow is more rapid than in most areas of the body as pulpal pressure is among the highest of body tissues.

Veins and venules that are larger than the arteries also appear in the central region of the root pulp. They exhibit much thinner walls in relation to the size of the lumen. Both venous - venous

anastomosis and arteriole-venous anastomosis occur in the pulp. The arteriole-venous shunts may have an important role in regulation of pulpal blood flow. Frequently arteriole or precapillary loops with capillaries are found underlying the odontogenic zone in the coronal pulp.

The terminal network of capillaries in the coronal pulp appears nearly perpendicular to the main trunks. A few peripheral capillaries found among the odontoblasts have fenestrations in the endothelial cells. These fenestrated capillaries are assumed to be involved in rapid transport of metabolites at a time when the odontoblasts are active in the process of dentinal matrix formation and its subsequent calcification.

Lymph Vessels

The presence of lymph vessels in the dental pulp is controversial. Lymph vessels draining the pulp and periodontal ligament have a common outlet. Those draining the anterior teeth pass to the submental lymph nodes; those of the posterior teeth pass to the submandibular and deep cervical lymph nodes.

Nerves

The abundant nerve supply in the pulp follows the distribution of the blood vessels. There are two types of nerve fibers—

- a. *Non- myelinated (sympathetic nerves)*—They are found in close association with the blood vessels of the pulp. They have terminals on the muscle cells of the larger vessels and function in vasoconstriction.
- b. *Myelinated (sensory)*—They are sensory nerves. Whatever be the nature of stimulation, the only sensation felt by pulpal nerves is that of pain. It cannot differentiate between heat, cold, touch, pressure or chemicals. It is due to the free nerve endings which are specific for pain. Pulpal nerve also cannot localize the pain as it does not have the receptors for proprioception.

The nerve fibers divide and redivide into smaller branches as they migrate coronally. They lose their myelin sheath and form a rich plexus in subodontoblastic zone. From this plexus nerves pass to odontoblastic layer, dentinal tubules and predentin.

Regressive Changes

1. *Cellular change*—In aging pulp, the cells are characterized by a decrease in size and number of cytoplasmic organelles. Number of cells are also become fewer.
2. *Fibrosis*—In aging pulp, accumulations of both diffuse fibrillar components as well as bundles of collagen fibers usually appear. There is sclerosis of vessels.

Pulp stone (denticles)—These are nodular, calcified masses in either or both coronal or root portion of the pulp organ.

A. Classification of pulp stone according to their structure.—(Fig. 7.4 A,B and C)

1. *True denticles*—contain dentinal tubules. They are very rare and located close to apical foramen. They are formed due to inclusion of epithelial root sheath in pulp followed by differentiation of odontoblast from pulp cell and formation of masses of dentin.
2. *False denticles*—do not contain dentinal tubules. They are concentric layers of calcified tissue with a remnant of necrotic cell in the center. Calcification of thrombi in blood vessel may also serve as nidus for false denticle.

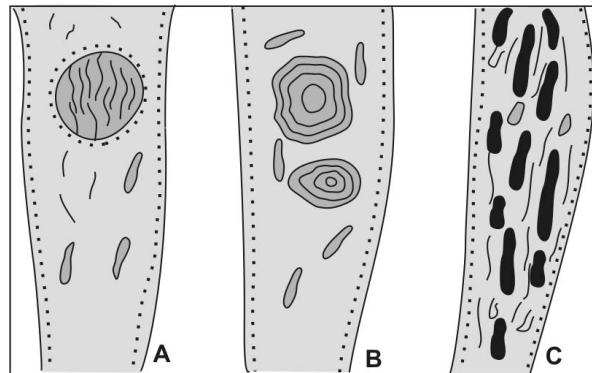


Fig. 7.4A to C: A. True denticles, B. False denticles, C. Diffuse calcification

3. *Diffuse calcifications*—These are irregular, calcific deposit in the pulpal tissue, usually following collagenous fiber bundles or blood vessels. Mostly they are found in root canal.
- B. Classification of pulp stone according to location—(Fig. 7.5A, B and C)

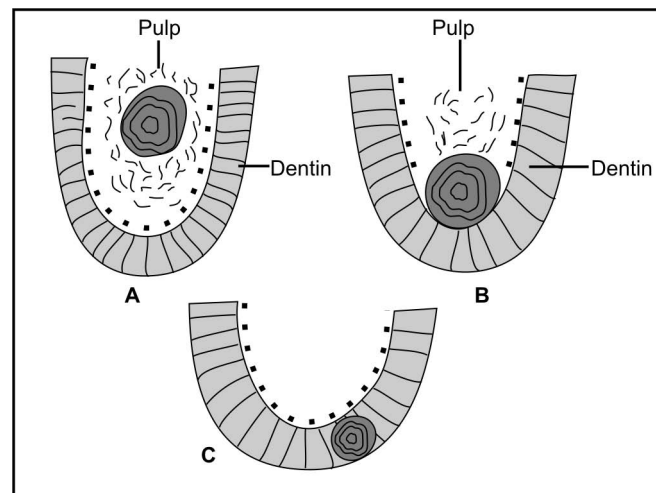


Fig. 7.5A to C: A. Free denticle, B. Attached denticle, C. Embedded denticle

1. Free denticles—They are entirely surrounded by pulp tissue.
2. Attached denticles—They are partly fused with dentinal wall.
3. Embedded denticles—They are completely embedded in dentin. .

Pulp stones may appear close to blood vessels and nerve trunks. The incidence as well as the size of pulp stones increase with age.

Clinical Considerations

1. For all operative procedures the shape of the pulp chamber and its extensions into the cusps, the pulp horns, are important to remember.

2. While performing root canal treatment, the size, shape, number and direction of pulp chamber, root canals and apical foramen must be kept in mind for successful treatment. Presence of pulp calcifications causes obstruction to root canal treatment.
3. The pulp is highly responsive to stimuli. Even a slight stimulus will cause inflammatory cell infiltration. A severe reaction is characterized as one with increased inflammatory cell infiltration adjacent to the cavity site, hyperemia or localized abscesses.

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Cementum

Cementum is a mineralized avascular connective tissue that covers the anatomic roots of teeth. It begins at the cervical portion of the tooth at the cemento-enamel junction and continues to the apex (Fig. 8.1). Cementum is a medium for the attachment of collagen fibers that bind the tooth to surrounding structures. It is a specialized connective tissue that shares some physical, chemical and structural characteristics with compact bone. But unlike bone it is avascular and has no innervation.

Physical Characteristics

1. Hardness—The hardness of fully mineralized cementum is less than dentin.
2. Color—Light yellow in color. It can be distinguished from enamel by its lack of luster and darker hue. It is lighter in color than dentin.
3. Permeability—It is permeable to a variety of materials. The cellular type is more permeable than acellular type. Permeability decreases with age.

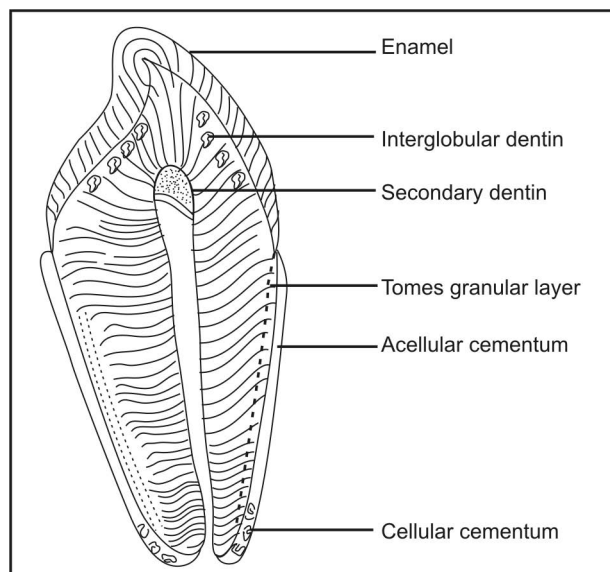


Fig. 8.1: Cementum

Chemical Composition

	<i>Weight</i>	<i>Volume</i>
Inorganic	65%	45%
Organic	23%	33%
Water	12%	22%

The inorganic portion consists mainly of calcium and phosphate in the form of hydroxyapatite. Numerous trace elements are found in cementum in varying amounts. Cementum has the highest fluoride content of all the mineralized tissues.

The organic portion of cementum consists primarily of type I collagen and protein polysaccharides (proteoglycans).

Functions

1. Attachment—The primary function of cementum is to furnish a medium for the attachment of collagen fibers that bind the tooth to alveolar bone.
2. Protection—It protects the root surface from injury and resorption by continuous deposition.
3. Reparative—Damage to roots such as fractures and resorptions can be repaired by deposition of new cementum.
4. Functional adaptation—Cementum makes functional adaptation of teeth possible by deposition of cementum in an apical area and thus can compensate for the loss of tooth substance from occlusal wear.
5. It helps eruption by apposition at apical end.
6. It helps to maintain the width of periodontal ligament.

Structure

With the light microscope two types of cementum can be differentiated—The classification is based on presence or absence of cells.

1. Acellular
2. Cellular

Acellular cementum—It is a type of cementum, that do not incorporate cells, the spiderlike cementocytes (Fig. 8.2). It is the first formed cementum and rate of development is relatively

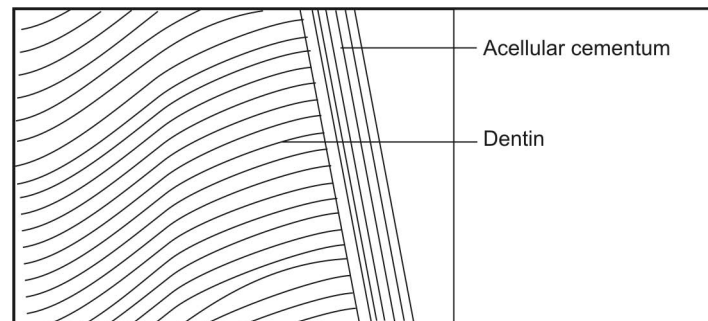


Fig. 8.2: Acellular cementum

slow. It covers the root and extended from cementoenamel junction to the apex, but it is often missing in the apical third of the root. It is the thinnest at the cementoenamel junction (20-50 μm) thicker near the apex or at bifurcation (150-200 μm). The apical foramen is surrounded by cementum. Sometimes cementum extends to the inner wall of dentin for a short distance.

It consists of—

- a. Collagen fibrils that make up the bulk of the organic portion of the tissue. The fibrils are arranged in a very complex fashion and usually arranged parallel to the root surface.
- b. *Sharpey's fibers*: These are discrete bundles of collagen fibrils, particularly seen in tangential section. They are the fibers of periodontal ligament, incorporated into the matrix of cementum (Fig. 8.3). They run at right angle to the collagen fibers.

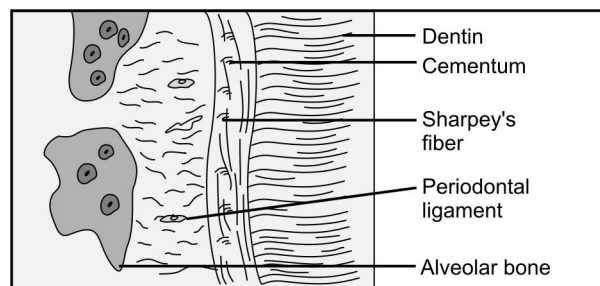


Fig. 8.3: Sharpey's fibers

In a zone, 10-50 μm wide near the cementodentinal junction, 1 to 5 μm unmineralized areas are seen. These areas probably represent poorly mineralized cores of Sharpey's fibers. When cementum remains relatively thin, Sharpey's fibers cross the entire thickness of the cementum. With further apposition of cementum, a larger part of the fibers are incorporated in the cementum. The attachment proper is confined to the most superficial or recently formed layer of cementum. This indicates that the thickness of cementum does not enhance functional efficiency by increasing the strength of attachment of the individual fibers.

Scanning electron microscopic features of Sharpey's fiber—In fully mineralized area, the center of Sharpey's fiber is exhibited by low rounded projections. In actively mineralizing front the sites where individual Sharpey's fibers enter the tooth are exhibited by numerous small openings. They represent the unmineralized core of the fiber.

- c. *Ground substance*—Interspersed between the collagen fibrils are electron-dense reticular areas which represent protein polysaccharide materials of the ground substance.

Cellular cementum—Cellular cementum is the type of cementum in which cementocytes are incorporated (Fig. 8.4). The rate of development is relatively fast. Cellular cementum is more frequently seen on apical half of root. Acellular cementum can occasionally be found on the surface of cellular cementum (Fig. 8.5). Cellular cementum is frequently formed on the surface of acellular cementum (Fig. 8.5), but it may comprise the entire thickness of apical cementum. It is always thickest around the apex and by its growth, contributes to the length of the root.

The cementocytes lie in spaces designated as lacunae (Fig. 8.6). A typical cementocyte has numerous cell processes or canaliculi radiating from its cell body. These processes may branch, and they frequently anastomose with those of a neighboring cell. Most of the processes are

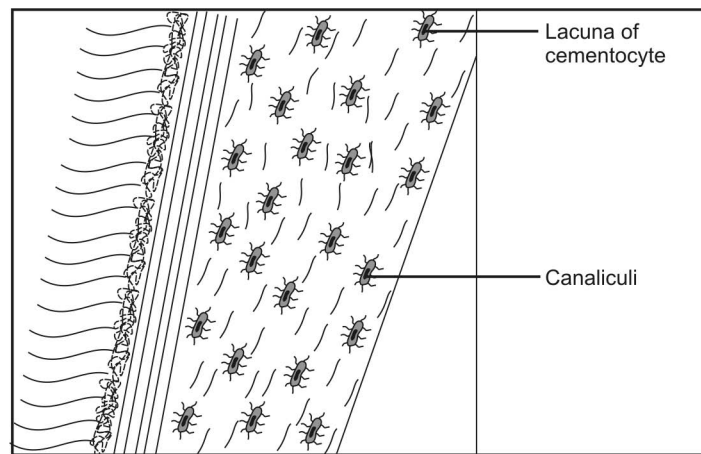


Fig. 8.4: Cellular cementum

directed towards the periodontal surface of the cementum. The cytoplasm of the cementocytes contain few organelles. The endoplasmic reticulum appears dilated, mitochondria are sparse. These features indicate that the cementocytes are in degenerating phase. At a depth of 60 μm cementocytes show cytoplasmic clumping and vesiculation. Sometimes the lacunae appear to be empty, suggesting complete degeneration of cementocytes.

Incremental lines of Salter—Cementum is deposited in an irregular rhythm, resulting in unevenly spaced incremental lines (Fig. 8.7). Both acellular and cellular cementum are separated by incremental lines into layers, which indicate periodic formation. In acellular cementum, incremental lines tend to be close together and they are thin and even. In the more rapidly formed cellular cementum, the lines are further apart and they are thicker and more irregular. The appearance of incremental lines in cementum is mainly due to differences in the degree of mineralization and also differences in composition of the underlying matrix.

Histochemical studies reveal that incremental lines are highly mineralized. They contain collagen and more ground substance.

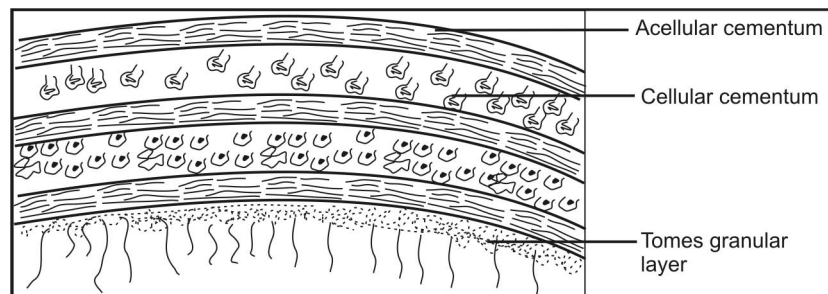


Fig. 8.5: Arrangement of cellular and acellular cementum

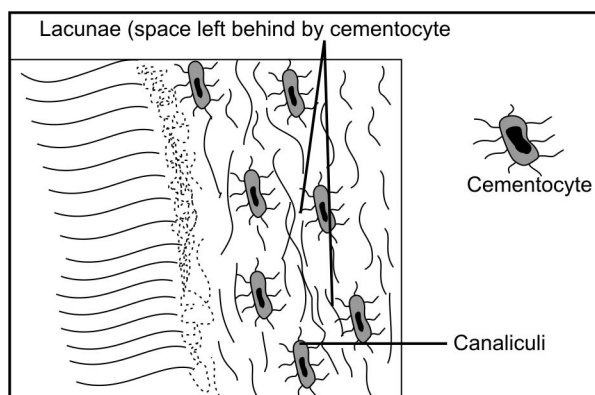


Fig. 8.6: Cementocyte

Table 8.1: Differences between acellular and cellular cementum

<i>Acellular</i>	<i>Cellular</i>
1. Absence of cells (cementocytes) in the calcified matrix.	1. Calcified matrix contains lacunae and canaliculi containing cementocytes and their processes.
2. Border with dentin is not clearly demarcated.	2. Border with dentin is clearly demarcated.
3. Rate of development is relatively slow.	3. Rate of development is relatively fast.
4. Incremental lines are relatively close together, thin and even.	4. Incremental lines are relatively wide apart, thick and irregular.
5. Precementum layer is narrow.	5. Precementum layer is wide.

Scanning Electron Microscopy

Extensive variations in the surface topography of cementum can be observed with the scanning electron microscope. Resting cemental surfaces, where mineralization is more or less complete, exhibit low, rounded projections corresponding to the centers of Sharpey's fibers. Cemental

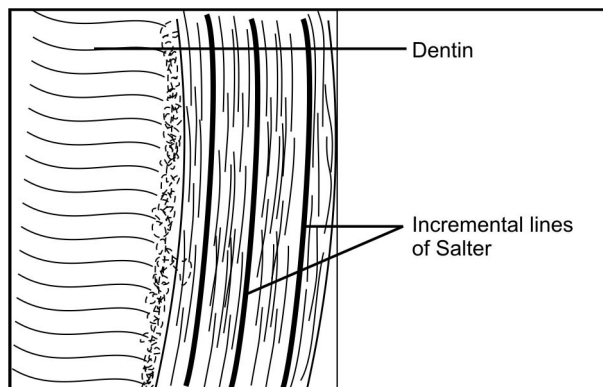


Fig. 8.7: Incremental lines of Salter

surfaces with actively mineralizing fronts have numerous small openings that correspond to sites where individual Sharpey's fibers enter the tooth. These openings represent unmineralized cores of the fibers. Numerous resorption bays and irregular ridges of cellular cementum are also observed on root surfaces.

Classification of Cementum Based on the Nature and Origin of the Organic Matrix

Cementum derives its organic matrix from two sources—

1. From the insertion of Sharpey's fibers of the periodontal ligament and these fibers are referred to as the extrinsic fibers.
2. From cementoblasts: These fibers are referred to as intrinsic fibers.

According to the nature and origin of the fibrous matrix the cementum is classified into—

1. *Extrinsic fiber cementum*—For this type of cementum all the collagen is derived as Sharpey's fibers from the periodontal ligament (ground substance is produced by cementoblast). These fibers continue into the cementum in the same direction as the principal fibers of the ligament (perpendicular or oblique to the root surface). This type of cementum corresponds with primary acellular cementum. It is therefore formed slowly and the root surface is smooth. The fibers are well mineralized.
2. *Mixed fiber cementum*—For this type of cementum, the collagen fibers of the organic matrix are derived from both extrinsic fibers and intrinsic fibers. The intrinsic fibers run between the extrinsic fibers with a different orientation. Indeed, the greater the number of intrinsic fibers in mixed fiber cementum, the greater the separation of the extrinsic fibers. The extrinsic fibers are ovoid or round bundles about 5-7 μm in diameter. The intrinsic fibers are 1-2 μm in diameter.

If the formation rate is slow, the mixed fiber cementum may be acellular and well mineralized. If the formation rate is fast, mixed fiber cementum may be cellular and less mineralized.

3. *Intrinsic fiber cementum*—This type of cementum is comprised only of intrinsic fibers running parallel to the root surface.

Cementodentinal Junction

[Discussed in brief in chapter 6, Dentin]

The interface between cementum and dentin is clearly visible in decalcified and stained histologic sections under light microscope. In such preparations cementum usually stains more intensely than does dentin.

Electron microscopically the cementodentinal junction is not very distinct. A narrow interface zone between the two tissues can be detected where cementum is more electron dense than dentin and some of its collagen fibrils are arranged in relatively distinct bundles while those of dentin are arranged somewhat haphazardly. Since collagen fibrils of cementum and dentin intertwine at their interface in a very complex fashion, it is not possible to determine whether fibrils are of dentinal or cemental origin.

Intermediate cementum—Sometimes dentin is separated from cementum by a zone known as the intermediate cementum layer, which does not exhibit the characteristic features of either

cementum or dentin. This layer is predominantly seen in apical two thirds of roots of molars and premolars and rarely observed in deciduous teeth and incisors. This layer represents the entrapped cells of Hertwig's epithelial root sheath in rapidly deposited dentin or cemental matrix. It may be found in continuous layer or in isolated areas.

Cementoenamel Junction

[Discussed in Chapter 5, Enamel]

Afibrillar Cementum

It is a type of cementum which contains no collagen fiber with a 64 nm periodicity. It is sparsely distributed and consists of a well mineralized ground substance which may be of epithelial origin. It is thin, acellular layer which covers cervical enamel or intervenes between fibrillar cementum and dentin.

Electron microscope evidence indicates that when connective tissue cells, probably cementoblasts, come in contact with enamel they produce a laminated, electron-dense, reticular material termed afibrillar cementum.

If such afibrillar cementum remains in contact with connective tissue cells for a long time, fibrillar cementum with characteristic collagen fibrils may subsequently be deposited on its surface.

Cementoblast—These are cementum forming cells, developed from undifferentiated mesenchymal cells of dental sac which come in contact with dentin after breakage of Hertwig's root sheath. Cementoblasts synthesize collagen and protein polysaccharides (proteoglycans), which form the organic matrix of cementum. These cells have numerous mitochondria, a well-formed Golgi apparatus, and large amount of granular endoplasmic reticulum.

Cementoid tissue—The calcified matrix of cementum is called cementoid. Under normal conditions, growth of cementum is a rhythmic process, and as a new layer of cementoid is formed, the old one calcifies. A thin layer of cementoid can usually be observed on the cemental surface. This cementoid tissue is lined by cementoblast.

Hypercementosis—(Fig. 8.8) Hypercementosis is an abnormal thickening of cementum, may be diffused or circumscribed. It may affect all teeth of the dentition, be confined to a single tooth, or even affect only parts of one tooth.

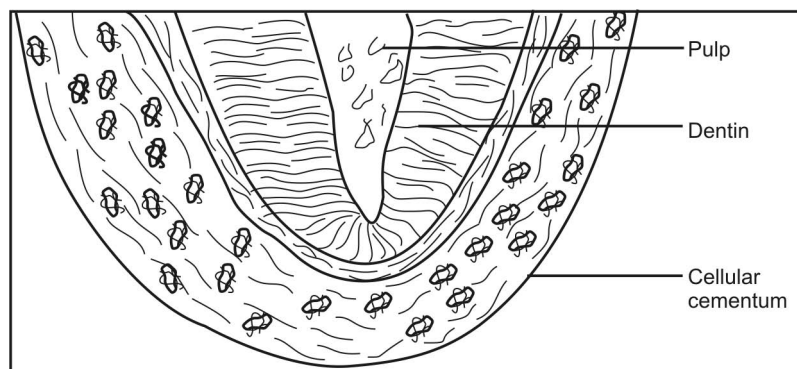


Fig. 8.8: Hypercementosis

Localized hypercementosis may be observed on enamel pearl (small protuberance of enamel). Occasionally it is irregular and sometimes contains round bodies that may be calcified epithelial rests. Such knob like projections are designated as excementoses.

Cementum hypertrophy—If the overgrowth improves the functional qualities of the cementum, it is termed as cementum hypertrophy.

In localized hypertrophy, a spur or prong like extensions of cementum may be formed. This condition is frequently found in teeth that are exposed to great stress. The prong like extensions of cementum provide a layer of surface area for the attaching fibers and thus a firmer anchorage of the tooth to the surrounding alveolar bone is assured.

Cementum hyperplasia—If the overgrowth occurs in nonfunctional teeth it is termed cementum hyperplasia. Extensive hyperplasia of cementum is usually associated with periapical inflammation. The hyperplasia may extend around the entire root of the nonfunctioning teeth or may be localized in small areas. There is reduction in number of Sharpey's fibers. In some cases an irregular overgrowth of cementum can be found as spike like extensions and calcification of Sharpey's fibers and accompanied by cementicles. These are usually associated with injuries of cementum.

Clinical Consideration

1. Cementum is a part of periodontium and gives attachment to periodontal ligament. Formation of cementum continues throughout life and therefore the periodontal ligament must alter or shift according to functional need. During continuous eruption, the width of the periodontal space widens. Deposition of cementum keeps this width constant. The root apex and the bifurcation of the roots are the places where this widening is greatest and therefore the thickness of cementum is also greatest in these areas.
2. The continuous formation of cementum is a compensatory reaction against shortening of the crown due to wearing of enamel.
3. Continuous eruption coupled with passive eruption diminishes the length of the clinical root. Deposition of cementum compensates for the deleterious effects of increased leverage due to shortened roots.
4. Cementum is more resistant to resorption than is bone. In careful orthodontic treatment, cementum resorption is minimal or absent but bone resorption leads to tooth migration.
5. Cementum being avascular is not easily damaged by a pressure equal to that exerted on bone.
6. Cementum resorption by trauma can be repaired by cellular or acellular cementum.

Anatomic repair—In these cases repair of cementum is done to re-establish the former outline of the root surface.

Functional repair—In these cases, repair after resorption is done both by cementum and bone to restore the periodontal width and to maintain the functional relationship.
7. In case of hypercementosis, normal extraction of teeth is not possible. These cases require surgical removal of tooth.

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Periodontium

The tissues which surround and support the tooth are collectively called the periodontium. They include the following:

- a. Cementum.
- b. Periodontal ligament.
- c. Alveolar bone.
- d. Gingiva, facing the tooth.

The supporting tissues of the tooth form a specialized fibrous joint known as gomphosis and develop from the dental follicle.

Periodontal Ligament

The periodontal ligament is the dense fibrous connective tissue which occupies the periodontal space between the root of the tooth and the alveolus. It surrounds the tooth root and anchors it to the bony socket. The tooth is attached to the alveolus by bundles of collagenous tissue, vessels and nerves. These fibers, known as the principal fibers, invest and surround the tooth and are called periodontal ligament. Above the alveolar crest, the ligament is continuous with connective tissues of the gingiva; at the apical foramen, it is continuous with the dental pulp and also communicates with marrow spaces of alveolar bone.

Function

1. Physical—
 - a. Attaches the tooth to the bone.
 - b. Transmits masticatory forces to the bone.
 - c. Acts as a shock absorber against external forces.
 - d. Maintains the relation between the tooth and the gingiva.
 - e. Gives protection to blood vessels and nerves by cushioning.
2. *Formative*—Cementoblasts are present in periodontal tissues which helps in formation of cementum through its cells.
3. *Nutritive*—The ligament transmits blood vessels which provide anabolites and other substances required by the cells of the ligament, such as cementoblasts, cementocytes and superficial osteocytes of alveolar bone. The blood vessels are also concerned with the catabolites.

4. *Sensory*—The nerves supply the blood vessels and also carry pain and proprioceptive sense of localization and pressure. Its mechano-receptors are involved in the neurological control of mastication.
5. *Homeostatic*—The cells of the periodontal ligament have the capacity to resorb and synthesize the extracellular substance of the connective tissue of ligament, alveolar bone and cementum.

Structure

The periodontal ligament consists of the following—

1. Fibers—
 - a. Collagen—over 90% of periodontal ligament fibers.
 - b. Oxytalan—Small amount.
 - c. Reticulin—Small amount.
2. Ground substance
3. Cellular elements
 - I. Connective tissue cells
 - A. Synthetic cells
 - a. Fibroblast
 - b. Osteoblast
 - c. Cementoblast.
 - B. Resorptive cells
 - a. Fibroblast
 - b. Osteoclast
 - c. Cementoclast
 - C. Progenitor cells
 - D. Defense cells
 - a. Mast cells
 - b. Macrophages.
 - II. Epithelial rests of Malassez.
4. Vessels- Arteries, veins and lymphatics.
5. Nerves.

FIBERS OF THE PERIODONTAL LIGAMENT

Collagen Fibers

The periodontal collagen is mostly Type-I collagen. It is low in hydroxylysine and glycosylated hydroxylysine. The periodontal ligament also contains 20% of Type-III collagen. It is high in hydroxyproline, low in hydroxylysine and contains cystine.

Much of the collagen is gathered together to form bundles which are approximately 5 μ m in diameter. They are organized into functional groups and are termed the principal fibers of the periodontal ligament. They follow a wavy course which straighten out under load. They are more numerous at alveolar bone. Collagen fibrils are the banded subunits of the collagen fiber. They are formed by the packing together of individual tropocollagen molecules.

The fibers are arranged in three sets—

1. The outer set—attached to bone and run towards cementum.
 2. The inner set—attached to cementum and run towards bone.
- Intermediate set—joins the outer and inner sets. This group is less matured.

The principal fibers are classified as follows—(Fig. 9.1).

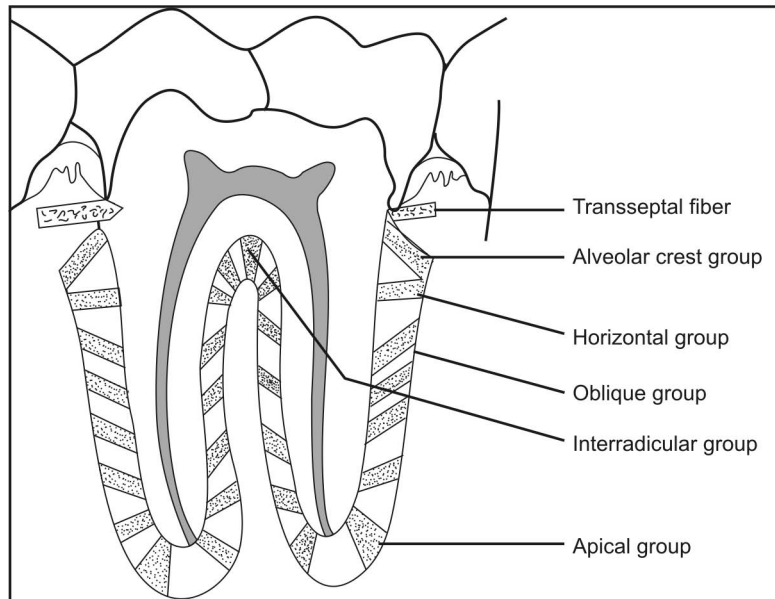
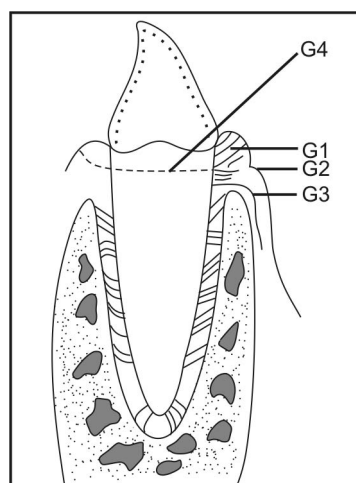


Fig. 9.1: Principal fibers of periodontal ligament

1. Gingival group
2. Transseptal group
3. Alveolar group
 - a. Alveolar crest group
 - b. Horizontal group
 - c. Oblique group
 - d. Apical group
 - e. Interradicular group
- I. Gingival group—(Fig. 9.2)



- G.1-From cementum to papillary gingiva
 G.2-From cementum to attached gingiva
 G.3-From cementum across alveolar crest and incline apically between periosteum and attached gingiva
 G.4-Circular bands around tooth

Fig. 9.2: Gingival fibers

These fibers extend from cervical cementum to free and attached gingiva. The part embedded in cementum is called Sharpey's fibers.

Functions

1. To support the gingiva, keeping it closely adapted to the tooth surface.
2. To sustain the gingiva against the forces of mastication.
3. To inhibit apical migration of the epithelial attachment.

Gingival fibers run in groups—Starting coronally and running apically they are.

Group 1. This group leave cementum near epithelial attachment at right angle, run a short course, bend occlusally and end in papillary gingiva.

Group 2. This group run from cementum straight across to attached gingiva.

Group 3. This group arise from cementum at right angle, cross over the alveolar crest, incline apically between the outer periosteum of alveolar process and epithelium of attached gingiva.

These groups keep the gingiva firmly against the tooth and keep the attached gingiva closely adapted to the underlying bone and tooth.

Group 4. Circular group—These fibers are circular bands around the teeth. They run over the transseptal fibers crisscrossing gingival fibers.

II. Transseptal Group—(Fig. 9.3) This is a dense group of fibers seen in proximal areas of teeth, extending from cementum of one tooth to the cementum of adjacent tooth. It forms a strong ligament connecting the necks of the adjacent teeth on their mesial and distal surfaces above the level of the interdental septum of the alveolar bone. These transseptal fibers link the individual units of the dentition together.

Function

- a. They support interproximal gingiva and secures adjacent teeth.
- b. After removal of a single tooth and the repair of its socket the transseptal fibers are reconstructed so as to connect the teeth on either side of the gap. The repair of these fibers, with the subsequent contraction of the fibrous tissue, is one of the factors responsible for

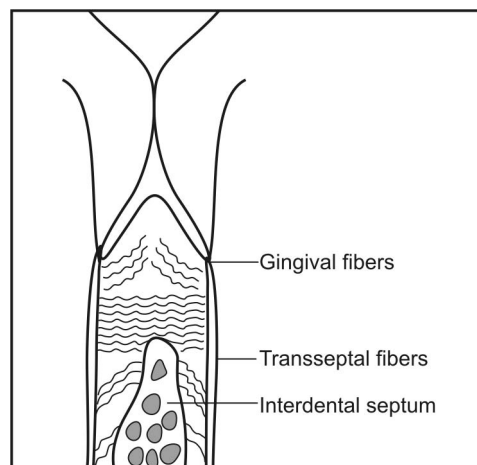


Fig. 9.3: Transseptal fibers

the tilting of the teeth on either side of the space left by the last tooth. The transseptal fibers have been shown to be important in the production of physiological mesial drift of the tooth.

- c. The transseptal fiber system is capable of turnover and remodelling under normal physiologic condition. Therefore a sufficiently prolonged retention period following orthodontic tooth movement would allow reorganization of the transseptal fiber system to ensure the clinical stability of the tooth position.

III. Alveolar Group—(Fig. 9.4)—This group of fibers extend from cementum to alveolus.

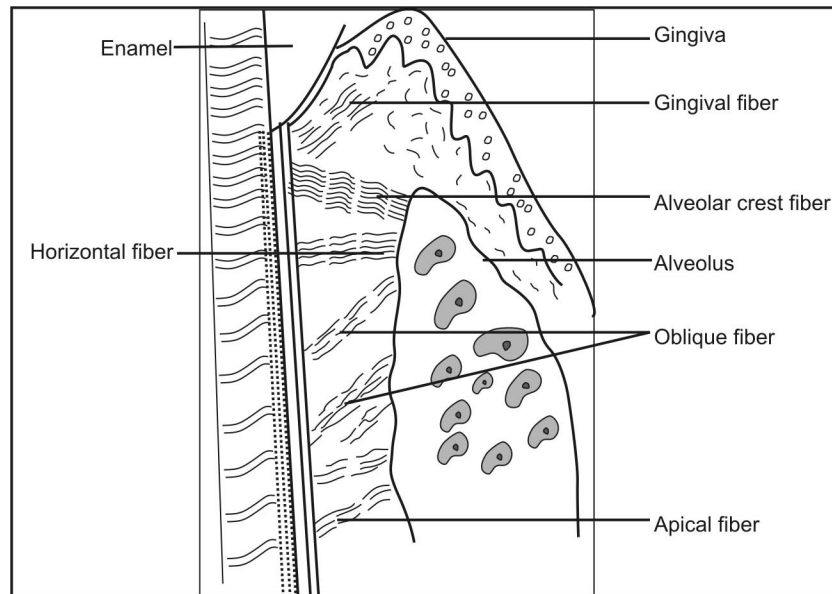


Fig. 9.4: Alveolar group of fiber

They run in five groups:

1. *Alveolar crest group*—These group of fibers are attached at one end to the cervical part of the cementum in relation to the buccal and lingual sides of the teeth. The fibers pass to the alveolar bone and are attached to the rim of the socket (alveolar crest).
Function—They anchor the tooth to the alveolus and oppose lateral stress. These fibers limit tilting and extrusion movements of the tooth.
2. *Horizontal group*—These fiber bundles extend from cementum at right angles to the long axis of the tooth to the bone.
Function—They resist tooth displacement against lateral pressure.
3. *Oblique Group*—These fiber bundles run obliquely from cementum to bone with cemental side apically and alveolar side coronally. These fiber bundles are most numerous and constitute the main attachment of tooth.
Function—They sustain occlusal stress and suspend the tooth in a socket.
4. *Apical Group*—The bundles of fiber extend from cementum in apical region to surrounding bone.
Function—They prevent vestibulo-oral tipping of tooth.

5. *Interradicular group*—(Fig. 9.5) These fiber bundles extend from crest of the interradicular septum to the cementum at furcation of multirooted teeth.

Function—They resist tipping and torquing.

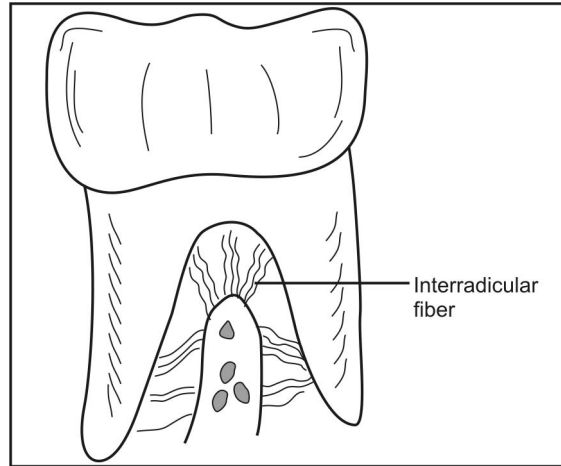


Fig. 9.5: Interradicular fiber

Intermediate plexus—Under the light microscope the principal fibers of the periodontal ligament arising from cementum and bone appear to be joined in the midregion of the periodontal space, giving rise to a zone of distinct appearance, the so called intermediate plexus (Fig. 9.6).

Electron microscopic and autoradiographic studies reveal that the intermediate plexus is an artifact arising out of the plane of section. The recent evidence suggests that the collagen fibers do not course only in one bundle but may move from one bundle to the other and join neighboring fibers to form a complex three dimensional network.

Though existence of intermediate plexus is controversial, there is a 'Zone-of-Shear-a site of remodelling in the periodontal ligament, which allows a tooth to move during eruption. It is either located in the center of periodontal ligament or close to the root surface.

Oxytalan fibers—Two immature form of elastic fiber named oxytalan and eluanin are present in periodontal ligament. The oxytalan fibers run parallel to the root surface in a vertical direction. It bends to attach to the cementum or possibly to the bone and the other end often in the wall of a blood vessel.

In the vicinity of the apex the oxytalan and the eluanin fibers form a complex network.

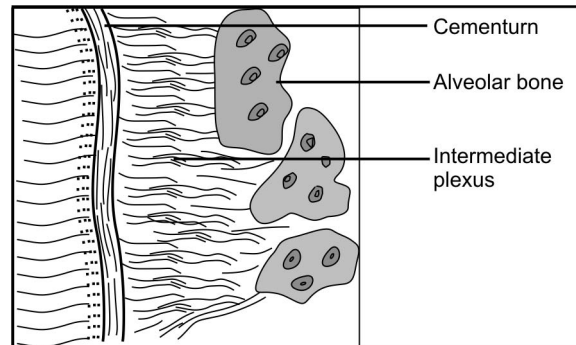


Fig. 9.6: Intermediate plexus

Function

1. They may play a part in supporting the blood vessels of the periodontal ligament.
2. They are also thought to regulate vascular flow.

Reticulin fibers—These fibers are related to the basement membranes within the periodontal ligament (i.e. associated with blood vessels and epithelial cell rests).

Ground Substance of the Periodontal Ligament

The ground substance of the periodontal ligament consists mainly of hyaluronate, glycosaminoglycans, proteoglycans and glycoproteins. All the components of the periodontal ligament ground substance are presumed to be secreted by the fibroblasts.

Function

1. Binding of ion and water.
2. Exchange of ion and water.
3. Control of fibrillogenesis and fiber orientation.
4. The tissue of fluid pressure has been found to be high in periodontal ligament (10 mm Hg above atmospheric pressure). Tissue fluid has been implicated in the tooth support and eruptive mechanisms.
5. A complex glycoprotein called fibronectin present in periodontal ligament promotes attachment of cells to collagen fibrils. As it is attached to cells, it is also involved in cell migration and orientation.
6. Another glycoprotein termed tenascin is present adjacent to alveolar bone and cementum. The role of this glycoprotein in the functions of the periodontal ligament is yet to be known.

Cells of the Periodontal Ligament (Fig. 9.7)*Synthetic Cells*

Fibroblast—The fibroblasts are the most common cells in periodontal ligament and appear as ovoid, elongated or fusiform in shape, oriented along the principal fibers and exhibiting pseudopodia like processes.

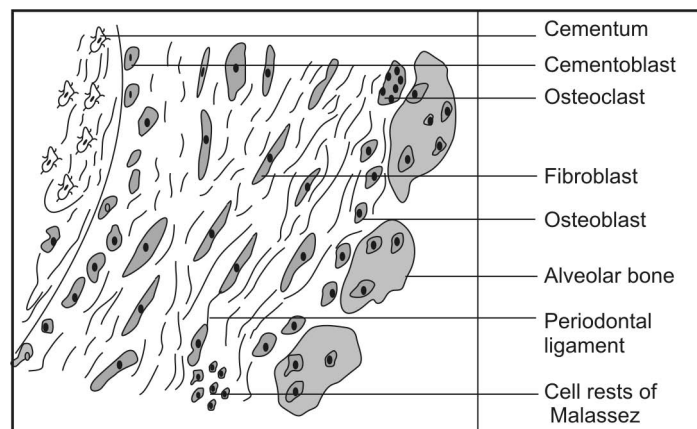


Fig. 9.7: Cells of the periodontal ligament

Function

1. Synthesis of collagen.
2. In vitro studies suggest that the periodontal fibroblasts are motile and contractile cells and they are capable of generating a force responsible for tooth eruption.

Osteoblast

The osteoblasts are present covering the periodontal surface of the alveolar bone.

Function

Synthesis of protein to constitute bony matrix.

Cementoblast

The cementoblasts in various stages of differentiation are seen on the cemental surface of periodontal ligament.

These three synthetically active cells when viewed under electron microscope, reveals—

1. Increased transcription of RNA
2. Production of ribosome,
3. Development of large quantities of rough endoplasmic reticulum (RER),
4. Presence of profuse Golgi saccules and vesicles,
5. Presence of large number of mitochondria.

Under the light microscope, the cells exhibit a large, open-faced or vesicular nucleus with prominent nucleoli and have abundant cytoplasm which is hematoxyphilic due to interaction of the RNA with the acid hematein in the stain.

Resorptive Cells

Fibroblast—The periodontal fibroblasts possess the capacity to phagocytose old collagen fibers and degrade them by the activity of proteolytic enzyme collagenase. Thus collagen turn over appears to be regulated by fibroblasts.

Osteoclast—These are the cells that resorb bone. Light microscopically the osteoclasts are

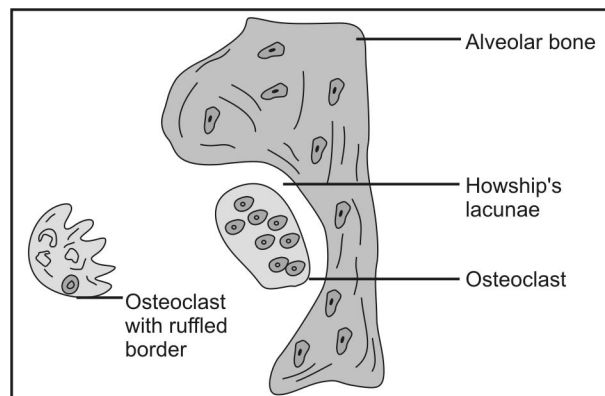


Fig. 9.8: Howship's lacunae

large, multinucleated or small, mononuclear cells, formed from circulating monocytes. They contain eosinophilic cytoplasm and occupy bays in bone known as Howship's Lacunae (Fig. 9.8).

Electron microscope reveals numerous mitochondria, lysosomes, Golgi saccules, ribosomes and little RER. The plasma membrane towards resorbing bone is raised in folds and is known as ruffled border. Osteoclasts are rich in acid phosphatase. Resorption of bone is accomplished by demineralization and disintegration of organic matrix.

Cementoclasts—They resemble osteoclasts and are located in Howship's Lacunae on the surface of the cementum.

Progenitor cells—The progenitor cells in the periodontal ligament replace the differentiated cells dying at the end of their life span or as a result of trauma.

They are small, close faced nucleus with little cytoplasm. They have the capacity to undergo mitotic division. The cells that divide in response to normal biologic requirements are located predominantly in the vicinity of blood vessels.

Defense Cells—(Fig. 9.9)

Mast cells—These are small, round or oval cell having 12-15 μm diameter. They have numerous cytoplasmic granule containing heparin and histamine. Mast cell histamine plays a role in the inflammatory reaction.

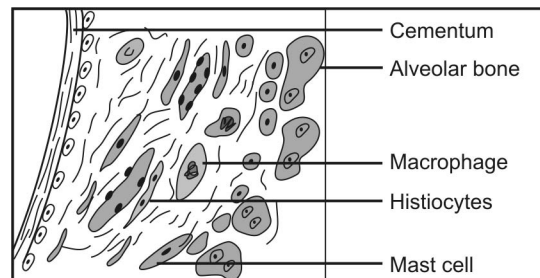


Fig. 9.9: Defense cells

Macrophages—These are derived from blood monocytes and are capable of phagocytosis. It contains horseshoe or kidney shaped nucleus which exhibits a dense uneven layer of peripheral chromatin. The surface of the cell is raised into microvilli and cytoplasm contains numerous free ribosomes and lysosomes in which phagocytosed material may be seen.

Epithelial rests of Malassez—These are the remnants of Hertwig's epithelial root sheath, described by Malassez in 1884. These are found close to the cementum in periodontal ligament. They persist as a network, strands, islands or tubule like structures near and parallel to the surface of the roots (Fig. 9.10).

Electron microscopic observations show that the epithelial cell rests exhibit tonofilaments and they are attached to one another by desmosomes. They are surrounded by a periodic acid schiff (PAS)- positive, argyrophilic fibrillar material, sometimes by hyaline capsule from which they are separated by basal lamina.

They diminish in number with age. Either they undergo degeneration or calcification to form cementicles.

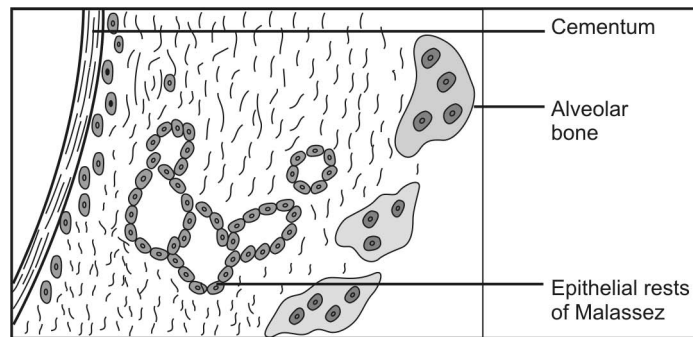


Fig. 9.10: Epithelial rests of Malassez

Their physiologic role in the functioning periodontal ligament is unknown. Under certain pathologic conditions, the cells of the epithelial rests undergo rapid proliferation and can produce a variety of cysts and tumors that are unique to the jaws.

Blood Vessels and Nerves of the Periodontal Ligament

Blood vessels—The arterial vessels of the periodontal ligament are derived from three sources—

1. From apical vessels that supply the dental pulp.
2. From intra-alveolar vessels. These branches run horizontally, penetrating the alveolar bone to enter the periodontal ligament.
3. From gingival vessels. These enter the periodontal ligament from coronal direction.

The arterioles and capillaries form a rich network in the periodontal space adjacent to the bone. There is a rich vascular plexus at the apex and in the cervical part of the ligament. The venous vessels tend to run axially to drain to the apex. There are numerous arteriovenous anastomoses and glomerulus like structure.

Lymphatics—A network of lymphatic vessels, follow the path of the blood vessels and flow from the ligament toward and into the adjacent alveolar bone.

Nerves—The periodontal ligament is well innervated. The nerve fibers entering the periodontal ligament are derived from two sources—

- a. The nerve bundles enter near the root apex and pass up through the periodontal ligament.
- b. The finer branches of the nerve enter the middle and cervical portions of the ligament through openings in the alveolar bone.

The nerves of the periodontal ligament are of two types—

1. *Non-myelinated*—They are autonomic nerves having the diameter of about 0.5 μm and supply the blood vessels.
2. *Myelinated*—The average diameter of myelinated nerve fibers is about 5 μm (some are having 15 μm diameter). They are sensory nerve fiber. The sensations felt by the nerves of the periodontal ligament are that of pain, pressure and touch through finer myelinated nerves and proprioception (sense of localization, chewing forces, movement, food texture, etc.) through larger myelinated nerves.

Cementicles-(Fig. 9.11)—These are calcified bodies located at any level of the periodontal ligament. They are more frequently encountered near the tip of the root. As isolated calcified bodies, fused to or incorporated in the cementum, they are known as free, adherent and interstitial cementicles respectively. They do not grow larger than 0.2 mm.

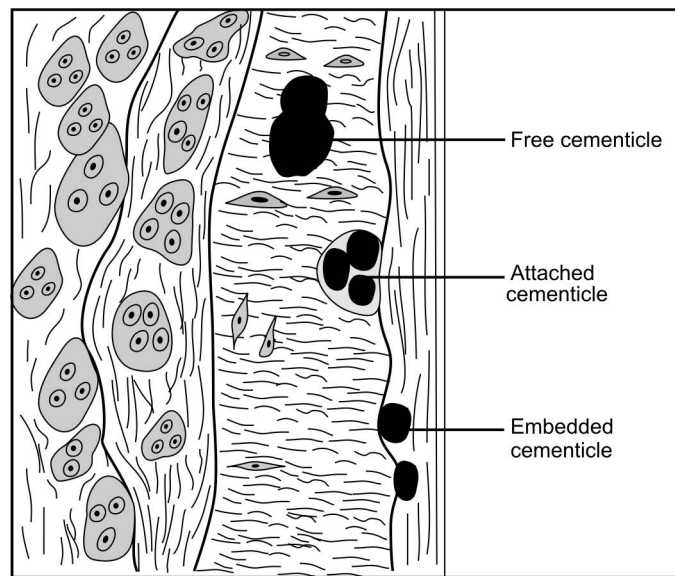


Fig. 9.11: Cementicles

They are composed of calcified layers surrounding degenerating cell remnants of Hertwig's epithelial rootsheath or phleboliths (vein stones).

Clinical Consideration

1. Orthodontic tooth movement depends on resorption and formation of both bone and periodontal ligament. These activities can be stimulated by properly regulated pressure and tension. The stimuli are transmitted through the medium of the periodontal ligament. If the movement of the teeth is within physiologic limits, the initial compression of the periodontal ligament on the pressure side is compensated for by bone resorption, where as on the tension side bone apposition is seen.
2. Inflammatory diseases of the pulp progresses to the apical periodontal ligament with the formation of granuloma.
3. Epithelial cell rests in periodontal ligament form cyst or neoplasm on stimulation.
4. Gingivitis or inflammation of the gingiva is the most common dental disease of humans. If not controlled or treated, it extends to the periodontal ligament and bone and produces their slow but progressive destruction.

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Alveolar Bone

The part of maxilla or mandible which supports and protects the teeth is known as alveolar bone (process). (Fig.10.1A and B). It is dependent on the presence of teeth for its development and maintenance. It is developed along with eruption of teeth and gradually atrophies after extraction or exfoliation of teeth.

Anatomically, no distinct boundary exists between the body of the maxilla or the mandible and their respective alveolar processes. An arbitrary boundary at the level of the apices of the teeth separates the alveolar processes from the body of the mandible and maxilla.

Functions

1. It forms the bony socket to hold the root of tooth as well as attaches it through the periodontal ligament.
2. It gives attachment to the muscle.
3. It provides a framework for bone marrow.
4. It acts as a reservoir for ion (especially calcium).
5. The most important biologic property of bone is its plasticity, allowing it to remodel according to the functional demands placed upon it. This property is essential for orthodontic tooth movement.

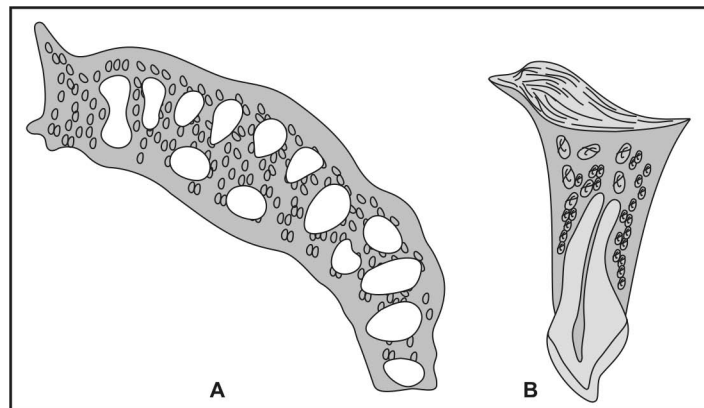


Fig. 10.1: Alveolar bone A. Horizontal section, B. Labiolingual section

Structure of Bone—Bone is a mineralized connective tissue. It is composed of

- a. Intercellular calcified material, known as Bone matrix.
- b. Bone cells.
- c. Periosteum and Endosteum.

a. *Bone matrix*—It has Inorganic component, Organic component and Water.

	By weight	By volume
Inorganic material	60%	36%
Organic material	25%	36%
Water	15%	28%

Inorganic—Calcium and phosphorus are abundant but bicarbonate, citrate, magnesium, potassium and sodium are also found. The mineral phase is hydroxyapatite, $[\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]$ in the form of needle-like crystallites or thin plates about 8 nm thick and of variable length.

Organic—About 90% of the organic material is present as Type I collagen. Ground substance contains proteoglycans and small amounts of other proteins like osteocalcin, osteonectin and osteopontin.

b. *Bone Cells*

- Osteoblast.
- Osteocytes.
- Osteoclast
- Osteoprogenitor cells.
- Bone lining cells.

Osteoblast—Osteoblasts are specialized fibroblast like cells of mesenchymal origin. They differentiate from progenitor cells of connective tissue. These are bone forming cells and are found on the surface in the area of active bone formation (Fig. 10.2). They are cuboidal with basophilic cytoplasm, prominent round nucleus towards basal end of the cell, extensive endoplasmic reticulum, golgi material, numerous mitochondria and vesicle. They are active in the formation of collagen fibrils and ground substance that constitute organic matrix. They produce homogeneous intercellular substance called osteoid tissue. They also take part in

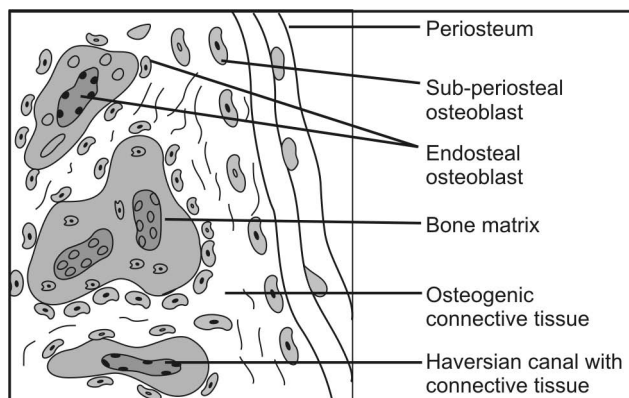


Fig. 10.2: Osteoblasts

calcification. Alkaline phosphatase is a useful marker for identification of cells at bony surfaces.

Osteocytes—Some osteoblasts are entrapped in osteoid tissue during its formation and are termed osteocytes (Fig. 10.3). They occupy a space called lacuna and anastomose with each other by means of processes contained in canaliculi. The processes of osteocytes communicate with each other and with the central canal of a Haversian system.

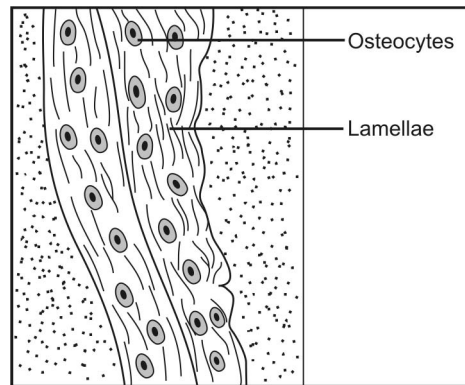


Fig. 10.3: Osteocytes

In ground section osteocytes are lost and lacunae appear black in transmitted light.

Osteocytes show few organelles revealing little sign of cellular activity. Osteocytes are thought to play a role in calcium homeostasis.

Osteoclast—The osteoclasts are large multinucleated cells responsible for resorption of bone. They arise as a result of fusion of blood cells of the myelo-monocyte cell line.

Osteoclasts are found in baylike depressions in the bone Called Howship's Lacunae (Fig.10.4). The part of the cell in contact with the bone shows a convoluted surface, the ruffled border, which is surrounded by a clear zone that has no organelles but only fine granular cytoplasm with microfilaments.

Acid phosphatase is used as a marker to identify the cells.

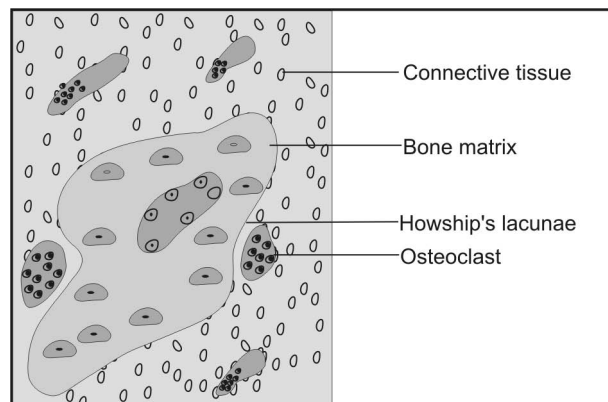


Fig. 10.4: Osteoclasts

Osteoprogenitor cells—These are mesenchymal, fibroblast like cells, regarded as forming a stem cell population to generate osteoblasts. They are situated in the vicinity of the blood vessels of the periodontal ligament.

Bone lining cells—When alveolar bone is not being deposited or resorbed, the surface is lined by relatively undifferentiated, flattened cells termed bone-lining cells.

They may be related to ion exchange and the process of osteoblasts (bone deposition) and osteoclasts (bone resorption).

c. **Periosteum and endosteum**—External and internal surfaces of bone are covered by layers of bone forming cells and connective tissue called periosteum and endosteum. The periosteum consists of an outer layer of collagen fibers and fibroblast and inner layer of osteoprogenitor cell (which differentiate into osteoblast).

The endosteum lines all internal cavities within the bone and is composed of a single layer of osteoprogenitor cells and a very small amount of connective tissue.

Function

1. Periosteum and endosteum provide nutrition to osseous tissue.
2. They supply new osteoblasts for repair and growth of bone.

Types of Bone Tissue

There are three types of bone tissue mature bone, immature bone and bundle bone.

Mature bone—The mature bone shows incremental lines or lamellae and are called lamellated bone. Each lamella is 4 to 12 μm thick. They are demarcated from each other by bands of intercellular cement approximately 0.1 μm thick. The collagen fibers within each lamella are parallel with each other, but have different orientation to those in adjacent lamellae. The osteocytes are evenly distributed. It can be compact or spongy bone.

Compact bone—The compact bone is thick and solid. The lamellae are arranged in the form of concentric cylinders surrounding a narrow canal. Each canal is surrounded by 5 to 20 lamellae, which are known as circumferential lamellae. The central vascular (Haversian) canal, together with concentric lamellae is known as Haversian system or osteon (Fig.10.5). A cement line of mineralised matrix (about 1 μm thick) delineates the Haversian system. The longitudinally running

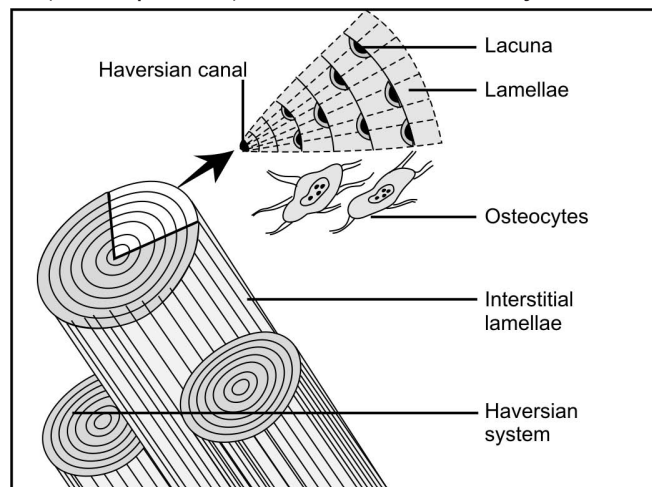


Fig. 10.5: Haversian system

Haversian canals are connected by transversely running Volkmann's Canals (Fig.10.6). Osteocytes through their canaliculi are in communication with the Haversian Canals.

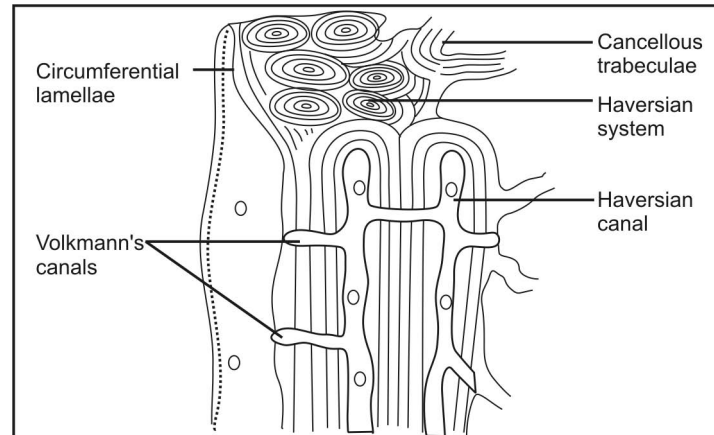


Fig. 10.6: Volkmann's canals

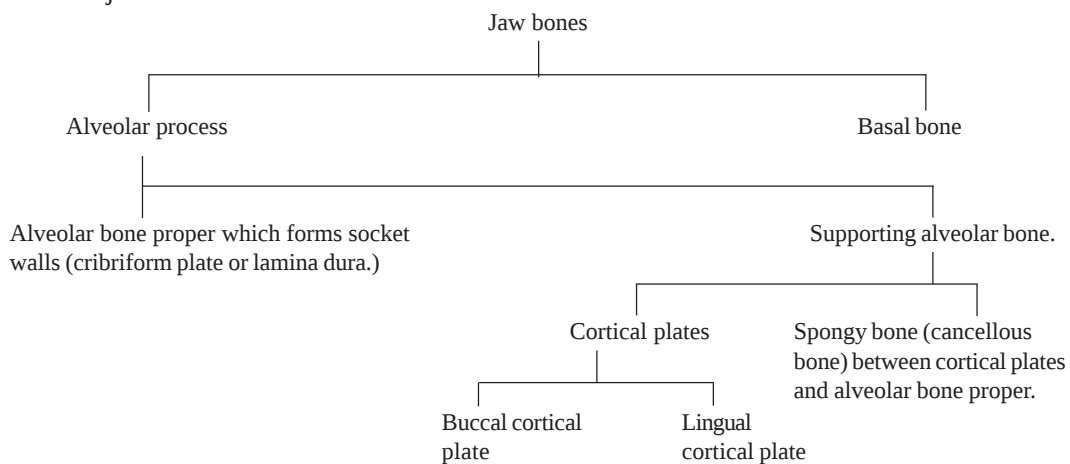
As a result of remodeling, fragments of previous Haversian systems may be present and are known as interstitial lamellae.

Spongy bone (cancellous bone)—In spongy bone, the lamellae are apposed to each other to form trabeculae about 50 µm thick. The marrow cavity is interrupted by a network of bony trabeculae which are not arranged randomly but aligned along lines of stress. These internal trabeculae support the outer cortical crust of compact bone.

Immature bone—There are more osteocytes than lamellated bone. The cells and collagen fibrils are arranged haphazardly. The fibrils are coarser and more in number. It contains less ground substance and it is less calcified..

Bundle bone—Collagen fibers of periodontal ligaments (Sharpey's fibers) are embedded in it. It is more calcified. This type of bone is restricted to alveolar bone proper.

Parts of jaw bone—



Alveolar bone or alveolar process (Fig.10.7). consists of two parts:

1. *Alveolar bone proper*—It forms the socket wall and gives attachment to the periodontal ligament. The alveolar bone proper, which forms inner wall of the socket, is perforated by many openings that carry branches of interalveolar nerves and blood vessels into the periodontal ligament. Therefore the alveolar bone proper is also known as cribriform (sieve like) plate.

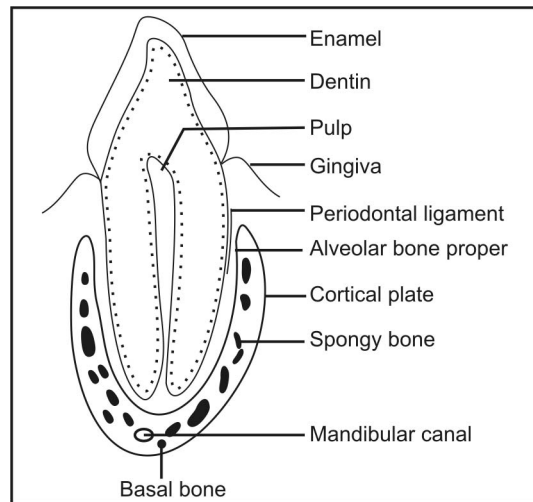


Fig. 10.7: Parts of alveolar bone

The alveolar bone proper consists partly of lamellated bone and partly of bundle bone (Fig.10.8). Some lamellae of lamellated bone are arranged roughly parallel to the surface of the adjacent marrow spaces, whereas others form haversian system.

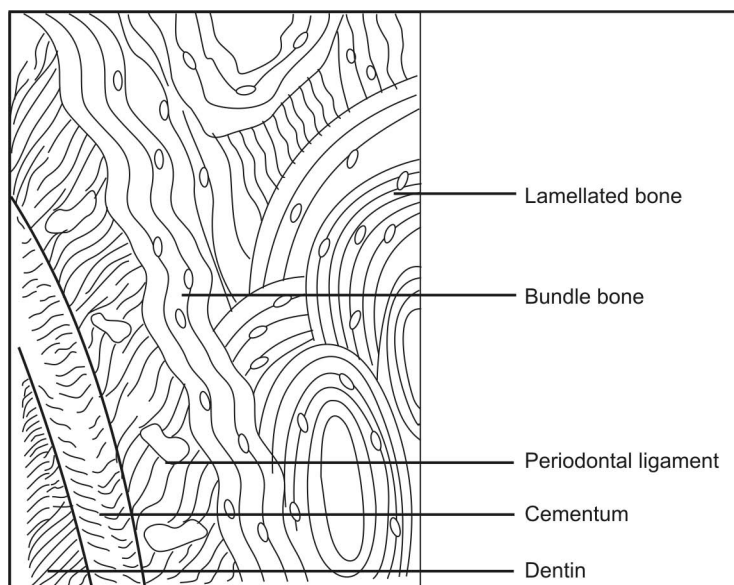


Fig. 10.8: Lamellated and bundle bone

Bundle bone is that bone in which the principal fibers of the periodontal ligament are anchored. It is termed as bundle bone as the bundles of the principal fibers continue into the bone as Sharpey's fibers. The bundle bone is characterized by the scarcity of the fibril which are arranged at the right angles to the Sharpey's fibers. As fibrils are less in bundle bone it appears darker in hematoxylin and eosin stained section and much lighter in preparations stained with silver compared to lamellated bone. Bundle bone contains more calcium salts per unit area than other types of bone tissue. Therefore in roentgenograms, bundle bones are seen as dense radiopacities and are known as lamina dura.

2. *Supporting alveolar bone*—It consists of two parts—

- a. *Cortical plates*: It is compact bone forming the outer and inner plates of alveolar processes (Fig.10.9). It is continuous with the compact layers of the maxillary and mandibular body.

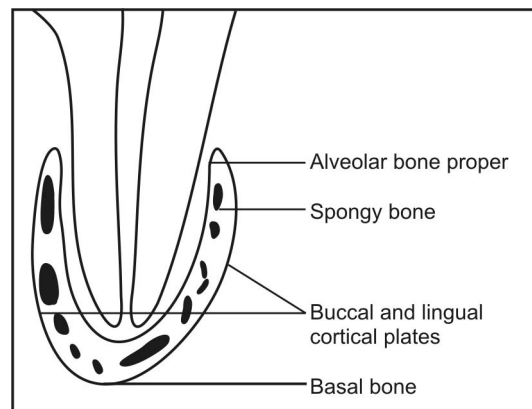


Fig. 10.9: Cortical plates

It is much thinner in the maxilla than in the mandible. In the maxilla the outer cortical plate is perforated by many small openings through which blood and lymph vessels pass. In the anterior region, supporting bone is very thin. No spongy bone is found in this region and the cortical plate is fused with the alveolar bone proper.

In the middle, the cortical bone of the alveolar process is dense. They are thickest in the premolar and molar region, especially on the buccal side. In the anterior region cortical plate is thin and is fused with the alveolar bone proper.

In a healthy mouth the distance between the cemento-enamel junction and the free border of alveolar bone proper is fairly constant (Fig.10.10A) and the shape of the outline of the crest of the alveolar septa is dependent on the position of the adjacent teeth. If the neighboring teeth are inclined, the alveolar crest is oblique (Fig.10.10B) which is most pronounced in the premolar and molar region.

The interdental septa contain perforating Canals of Zuckerkandl and the interradicular septa contain Canals of Hirschfeld which house the interdental and interradicular arteries, veins, lymph vessels and nerves.

Histologically, the cortical plates consist of longitudinal lamellae and Haversian systems.

- b. *Spongy bones*—It is the cancellous bone between cortical plates and alveolar bone proper (Fig.10.11). Radiologically the spongy bone is of two types.

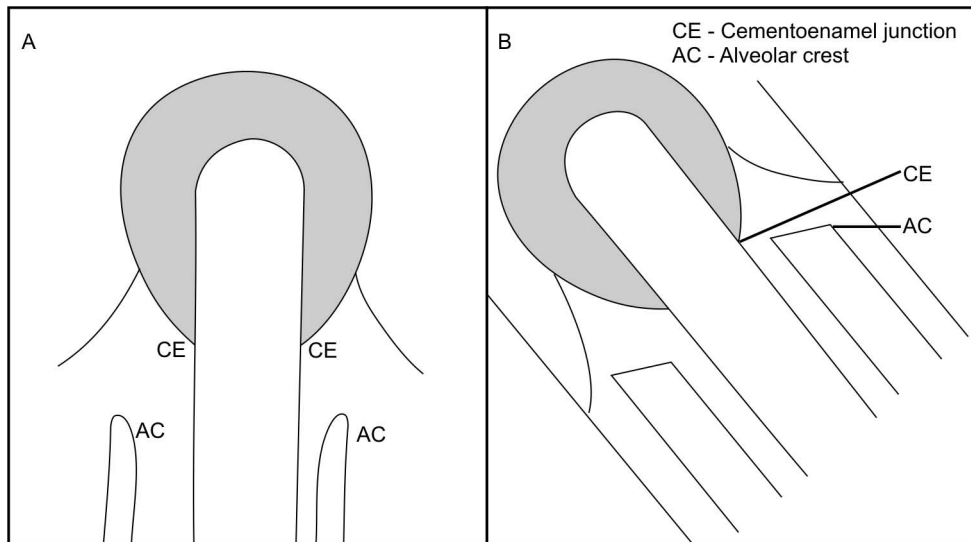


Fig. 10.10A and B: Relation between cementoenamel junction of adjacent teeth and shape of alveolar crest

Type I—Interdental and interradicular trabeculae are regular and horizontal in a ladder like arrangement (Fig.10.12). It is mostly seen in mandible and shows the trajectory pattern of spongy bone.

Type II—It shows irregularly arranged, numerous, delicate interdental and interradicular trabeculae (Fig.10.13). It lacks a distinct trajectory pattern. This arrangement is more common in maxilla.

The marrow spaces in the process usually contain fatty marrow. In the condylar process, angle of the mandible, maxillary tuberosity region, hematopoietic cellular marrow is found.

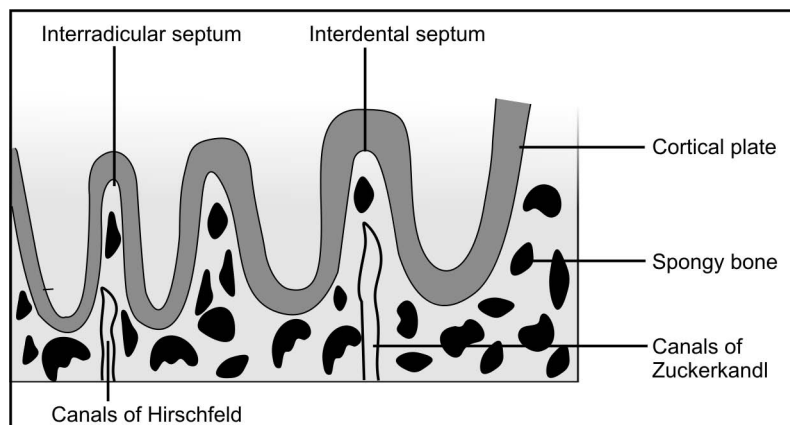


Fig. 10.11: Spongy bone

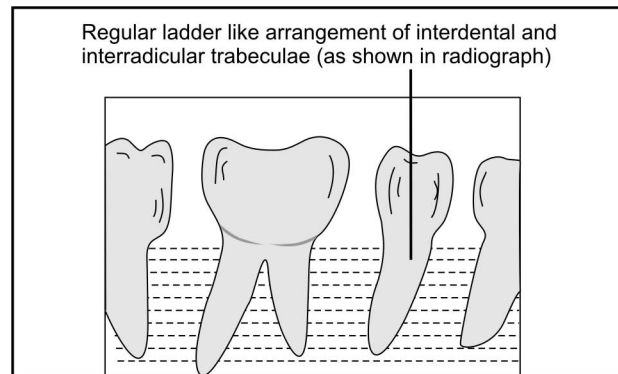


Fig. 10.12: Type I alveolar spongiosa

Physiologic Changes in Alveolar Process

In the jaws, structural changes are correlated to the growth, eruption, movements, wear and loss of teeth. All these processes are made possible only by a coordination of destructive and formative activities.

Osteoblasts secrete the type I collagen and noncollagenous organic matrix. The unmineralized matrix is osteoid tissue. Hydroxyapatite crystals are deposited on and in between the molecules of collagen and non-collagenous organic matrix. A superficial layer of osteoid tissue is present as mineralization always lags behind the production of bone matrix. Some osteoblasts are embedded in the matrix and are known as osteocytes. Enzymes responsible for synthesis of bone are (1) ATPase (2) alkaline phosphatase (3) pyrophosphatase. Osteoclasts are responsible for resorption of bone. During bone resorption, three processes occur in more or less rapid succession. (1) Decalcification (2) Degradation of matrix (3) Transport of soluble products to extracellular fluid or blood vascular system.

Bone decalcification is achieved at the ruffled border of the osteoclast by secretion of citric acid and lactic acid.

After decalcification, pieces of matrix are released by the activity of cathepsin B-1 (Lysosomal acid protease) and collagenase enzymes.

After degradation of the matrix, the breakdown products of bone are transported to the extracellular fluids and to blood vascular system.

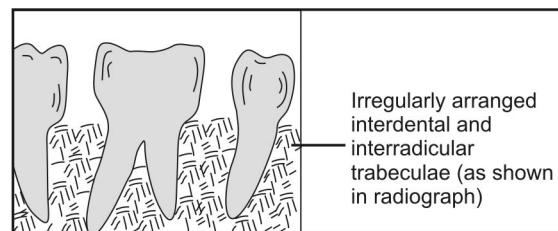


Fig. 10.13: Type II alveolar spongiosa (Diagram of Radiological Feature)

Internal reconstruction of bone-

Remodelling is a natural process occurring in most bones throughout life. This activity is especially important to the alveolar process during—

- Physiologic eruptive movements of the teeth.
- Physiologic mesial drift.
- Orthodontic mesial or distal movements of teeth.

Resting lines—Bone is laid down rhythmically and results in formation of regular parallel lines (Fig.10.14) which, because they are formed in periods of relative quiescence are termed as Resting lines. These lines are prominent in bundle bone during drift of teeth.

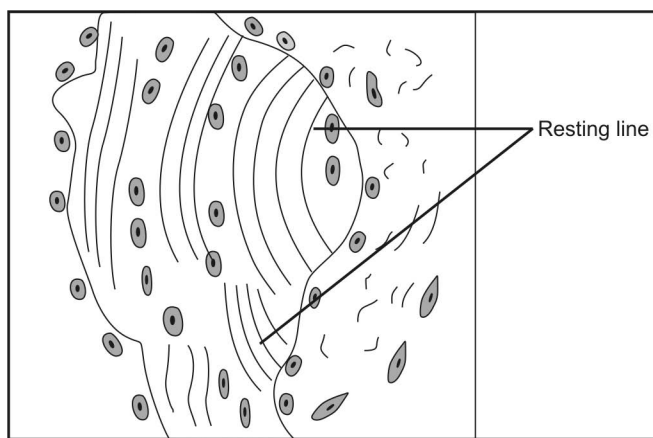


Fig. 10.14: Resting lines of bone

Resorption tunnel—When the bone undergoes osteoclastic activity, the resorbed bone is replaced by proliferating loose connective tissue. This area of resorption is called the Resorption tunnel or cutting cone.

Reversal lines—These are intensely hematoxyphilic scalloped line seen at the junction of resorbed bone and the new bone formed after ceassation of resorption. They are irregular scalloped line, being composed of series of concavities, which were once the sites of the resorptive Howship's lacunae (Fig.10.15). During remodeling, the compact bone may be replaced by spongy bone or

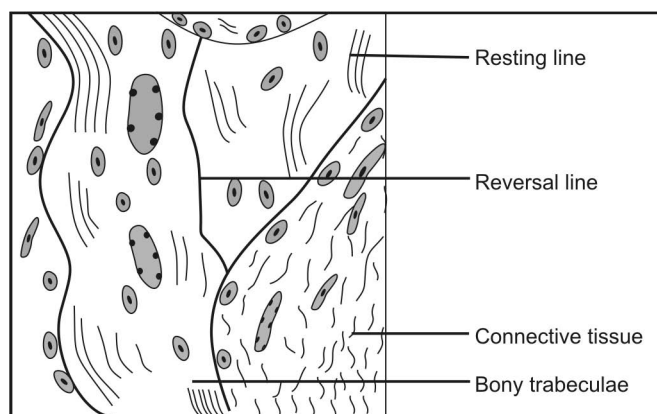


Fig. 10.15: Reversal lines of bone

spongy bone may change into compact bone. This is known as internal reconstruction of bone.

Clinical Considerations

1. Bone, being highly plastic enables the orthodontic movement of teeth. Bone is resorbed on the side of pressure with the help of cyclic adenosine monophosphate (cAMP) and apposed on the side of tension.
2. During healing of fractures or extraction wounds, an embryonic type of bone is formed which is later replaced by mature bone.
3. Periodontal disease leads to resorption of alveolar bone.
4. Synthetic inorganic products are currently used for the augmentation of the alveolar ridges and for filling bone defects produced by periodontal disease.
5. After exfoliation of tooth, alveolar bone undergoes gradual atrophy. Sometimes resorption is so severe that the fabrication of a functional prosthesis may become difficult.

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Oral Mucous Membrane

The moist lining of oral cavity is known as oral mucous membrane or oral mucosa. At the lips the oral mucosa is continuous with the skin and at the pharynx it is continuous with the moist mucosa lining the rest of the intestine. It has a superficial epithelial lining and a deeper connective tissue layer. The epithelium of oral mucosa anterior to buccopharyngeal membrane is ectodermal in origin.

Skin—The oral mucous membrane resembles skin in many ways but it differs in certain aspects.

Table 11.1: Differentiating features between skin and oral mucosa.

<i>Skin</i>	<i>Oral mucosa</i>
1. Skin provides covering for the external surface of the body.	1. Oral mucosa covers the oral cavity from vermilion zone to pharynx.
2. It is pale brown in color.	2. It is coral pink in color.
3. It has dry surface with folds, wrinkles.	3. It has moist, smooth surface (except dorsum of tongue and palatine rugae).
4. It is composed of two different layers known as epidermis and dermis or corium.	4. It is composed of two different layers known as epithelium and lamina propria.
5. Skin contains numerous hair follicles sebaceous glands and sweat glands.	5. The glandular component of oral mucosa is represented by minor salivary gland.

Functions of the Oral Mucosa

1. **Protection**—The oral mucosa separates and protects deeper tissues and organs in the oral region from mechanical forces like compression, stretching and shearing at the time of biting and chewing food. The epithelium of oral mucosa provides a barrier to micro-organisms, toxins and various antigens.
2. **Sensation**—In the oral cavity, there are receptors that respond to temperature, touch and pain. There are also taste buds, which are not found anywhere else in the body. Certain receptors in the oral mucosa respond to the taste of water and signal the satisfaction of thirst. Reflexes such as swallowing, gagging, retching and salivating are also initiated by receptors in the oral mucosa..
3. It has a role in immunological defence, both humoral and cell mediated.
4. Minor salivary glands within the oral mucosa provide lubrication and buffering as well as secretion of some antibodies.

5. *Digestive function*—Food is tasted, masticated and the saliva secreted into oral cavity lubricates the food to facilitate swallowing. Enzymes in saliva initiate digestion in oral cavity.
6. *Thermal regulation*—In some animals (dog) the mucosa plays a major role in regulation of body temperature as considerable body heat is dissipated through the oral mucosa by panting.

Organization of the Oral Mucosa

The oral cavity consists of two parts:

1. Vestibule—bounded by the lips and cheeks.
2. Oral cavity proper
 - Anteriorly—Separated from the vestibule by the alveolus, bearing the teeth and gingiva.
 - Superiorly—Hard and soft palate.
 - Inferiorly—Floor of the mouth, base of the tongue.
 - Posteriorly—Pillars of the fauces and the tonsils.

Classification of Oral Mucosa: (According to Function)

1. *Masticatory mucosa*—This is a type of mucosa which is subjected to friction due to mastication. The masticatory mucosa tends to be bound to bone and does not stretch. It bears forces generated when food is chewed, e.g. - mucosa of gingiva and hard palate. (Figs 11.1 and 11.2)
2. *Lining mucosa*—This is a type of mucosa which is subjected to less friction due to mastication. It covers musculature and is distensible, adopting itself to the contraction and relaxation of cheeks, lips and tongue and to the movement of mandible produced by muscles of mastication, e.g. - lips, cheeks, vestibule, inferior surface of tongue, floor of the mouth, soft palate (Figs 11.1 and 11.2).

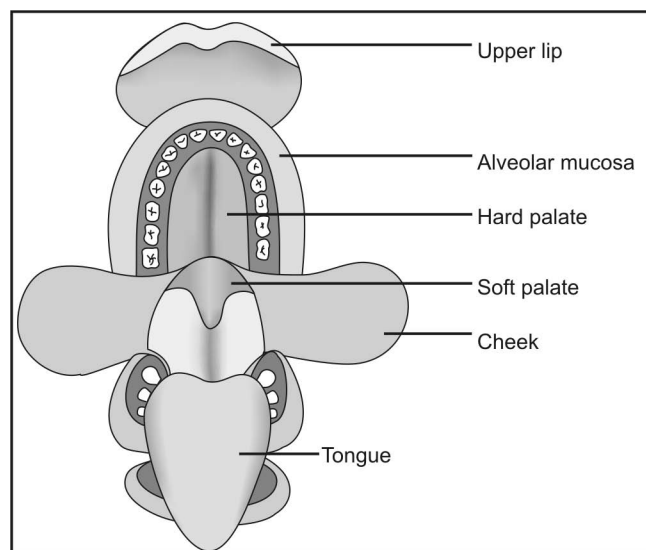


Fig. 11.1: Anatomic location of different types of mucosa in oral cavity—part A

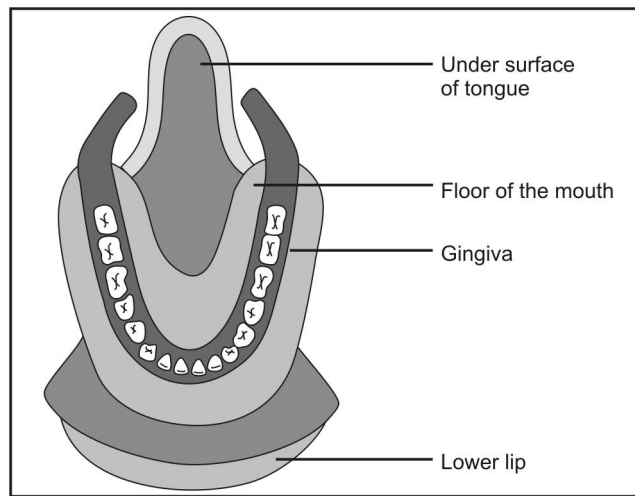


Fig. 11.2: Anatomic location of different types of mucosa in oral cavity—Part B

3. *Specialized mucosa*—The specialized mucosa is so called because it bears the taste buds, which have a sensory function, e.g. - dorsum of tongue.

Clinical Appearance

1. *Color*—The usual color of oral cavity is coral pink. The color depends upon—
 - a. Thickness of epithelium.
 - b. Degree of keratinization.
 - c. State of dilatation of small blood vessels in the underlying connective tissue.
 - d. Amount of melanin in epithelium.
2. It is moist as salivary glands pour their secretion into it.
3. Sometimes sebaceous glands of skin are present in oral mucosa and are manifested as pale yellow spots known as Fordyce's Spots.
4. In general the oral mucosa is smooth except dorsum of tongue (due to presence of papillae/ rugae)
5. The healthy gingiva shows a pattern of fine surface stippling, consisting of small indentations of the mucosal surface.
6. *Linea alba*—this is a whitish keratinized ridge along buccal mucosa in the occlusal plane of the teeth and represent the effect of abrasion from surface of tooth.
7. The oral mucosa varies considerably in its firmness and texture. The lining mucosa of the lips, cheeks is soft and pliable where as gingiva and hard palate are covered by a firm and immobile layer.

Component Tissues of Oral Mucosa

The main tissue components of oral mucosa are—

- a. Oral epithelium.
- b. Lamina propria.

- c. Submucosa.
- d. Mucoperiosteum.

Oral epithelium—The epithelium of the oral mucous membrane is of the stratified squamous variety. It may be keratinized and non-keratinized, depending on location.

Masticatory mucosa (gingiva and hard palate) and specialized mucosa (dorsum of tongue) are keratinized.

Lining mucosa (cheek, lip, floor of the mouth, under surface of tongue, alveolar mucosa, vestibule, soft palate) are non-keratinized.

The cells of the epithelium consist of two functional populations—

- a. A progenitor population—Its function is to divide and provide new cells.
- b. A maturing population—The cells in this group continually undergo a process of differentiation or maturation to form a protective surface layer.

After cell division, each daughter cell makes the decision either to recycle in the progenitor population or to enter the maturing compartment. The decision making period is known as the dichophase.

Turnover time of epithelium is the time taken by a cell to divide, pass through the entire epithelium and to desquamate from the surface.

It is 41-51 days in gingiva and 25 days in the cheek mucosa.

Cell division, growth and differentiation of oral epithelium are regulated by a soluble glycoprotein, Cytokine.

Keratinized Oral Epithelium

The different layers (Fig. 11.3)

- a. The basal cell layer (stratum basale).
- b. The spinous cell layer (stratum spinosum).
- c. The granular cell layer (stratum granulosum).
- d. The keratinized layer (stratum corneum).

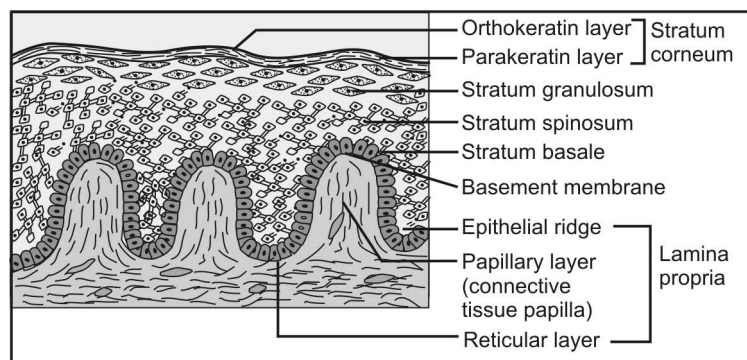


Fig. 11.3: Histology of keratinized oral epithelium

The Basal Cell Layer (Stratum Basale)

The basal cell layer is a layer of cuboidal or columnar cells adjacent to the basement membrane. The basal cells and some superficial parabasal cells are capable of cell division. So they are also known as stratum germinativum.

The basal cells are attached to underlying basement membrane and connective tissue by hemidesmosomes (Fig. 11.4). The lateral borders of adjacent basal cells are closely apposed and connected by desmosomes (Fig. 11.5). The basal cells contain tonofilament in relation to desmosome and hemidesmosomes. There are also tight, and gap junctions present. Ribosomes and rough endoplasmic reticulum are indicative of protein synthesizing activity. Nucleolus, mitochondria, golgi material are also present.

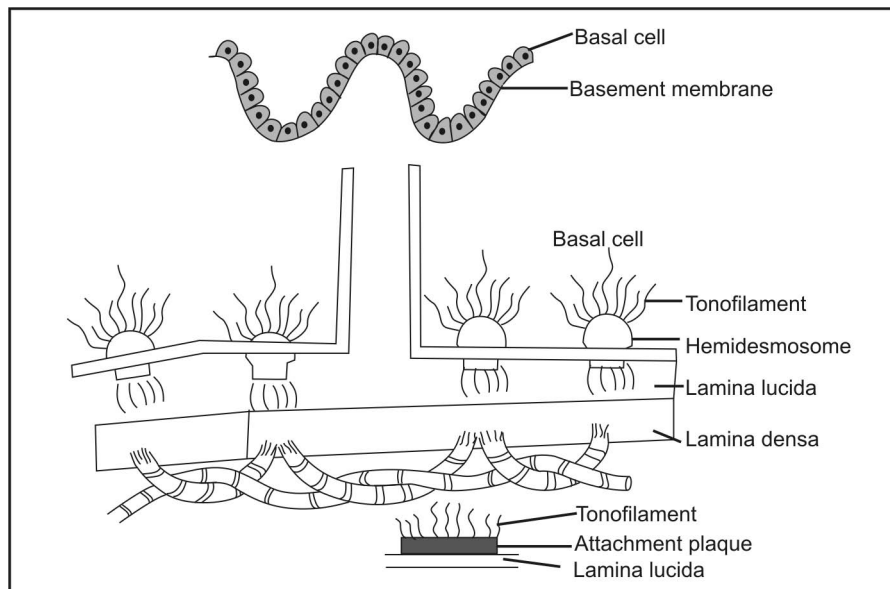


Fig. 11.4: Hemidesmosome

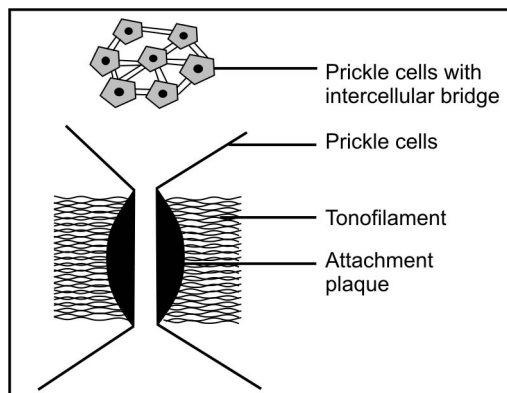


Fig. 11.5: Desmosome

[Desmosomes are circular or oval areas of adjacent cell membranes, adhering by specialized intracellular thickenings known as attachment plaque (formed by a protein known as desmoplakin) into which bundles of tonofilaments insert. These filaments loop around within the plaques and pass out again without crossing the adjacent cells. During histologic processing, the desmosomes usually remain intact, which appear as intercellular bridges light microscopically. Adhesion between basal cells and connective tissue is provided by hemidesmosomes which are present on basement membrane of basal cells. They possess single attachment plaque with tonofilaments inserted.

The desmosomes, hemidesmosomes, and tonofilaments form a mechanical linkage that distributes and dissipates localized forces applied to the epithelial surface over a wide area.

The gap junction is the region where membranes of adjacent cells run closely together, separated by only a small gap. There appear to be small interconnections between the membranes across these gaps. Such junctions may allow electrical or chemical communication between the cells.

The tight junctions are so tightly apposed that there is no intercellular space. These junctions may serve to seal off and compartmentalize the intercellular area].

The Prickle Cell Layer (Stratum Spinosum)

Above the basal cells, there are several rows of irregularly polyhedral cells, longer than basal cells. They are known as prickle cell layer or stratum spinosum.

Light microscopically it appears that the cells are joined by “intercellular bridges”.

Electronmicroscopically the “intercellular bridges” are desmosomes and tonofilaments.

These spinous cells are most active in protein synthesis.

[The term prickle arises from prickly appearance of the cells. During histological preparations, the cells shrink and are attached to one another at the site of desmosomes which give a spiny or prickle like profile. Greek word for prickle is acanthi. So the increased thickness of prickle cells is known as acanthosis and separation of the prickle cells by degeneration of intercellular bridges is termed as acantholysis].

The Granular Cell Layer (Stratum Granulosum)

Superficial to the prickle cell layer, there are larger flattened cells containing small granules that stain intensely with acid dyes such as hematoxylin (i.e they are basophilic). This layer is the granular layer, or stratum granulosum and the granules are called keratohyaline granules. In gingiva these granules are difficult to see under light microscope as they are masked by the superficial nucleated keratin layer.

Though this layer still synthesizes protein, the nuclei show signs of degeneration and pyknosis. Tonofilaments are more dense in quantity and are associated with keratohyaline granule.

The membrane coating granules known as keratinosome or Odland body are found in upper spinous and granular cell layer. They discharge their contents into intercellular space forming an intercellular lamellar material, which contributes to the permeability barrier.

The Keratinized Layer (Stratum Corneum)

The surface layer or stratum corneum is composed of flat cells, stained bright pink with eosin and do not contain nuclei, ribosome, mitochondria and keratohyaline granule. The pattern of maturation of the cells to form anucleated squames is known as orthokeratinization.

The masticatory mucosa (e.g. parts of the hard palate and much of the gingiva) reveals a variation of keratinization where the surface layer shows pyknotic nuclei and partially lysed cell organelles. This process is known as Parakeratinization.

The keratinized cell becomes compact and dehydrated and covers a greater surface area than basal cells and prickly cells but smaller than granular cells.

Ultrastructurally the cells of the cornified layer are composed of densely packed filaments developed from the tonofilaments, altered and coated by the basic protein of the keratohyaline granule, filaggrin. There is also a sulphur rich component called loricrin.

The dehydrated squames of keratin are shed in few hours and are replaced by cells from underlying layers.

The epithelial cells that ultimately keratinize are called keratinocytes. All epithelial cells have intermediate filaments made of keratin.

Nonkeratinized Oral Epithelium

It does not produce cornified surface layers.

The different layers (Fig. 11.6)

- a. The basal cell layer (stratum basale)
- b. The intermediate cell layer (stratum intermedium)
- c. The superficial cell layer (stratum superficial)
- a. *The basal cell layer*—The cells are similar to the basal cells of keratinized oral epithelium.
- b. *The intermediate cell layer*—The cells are larger than prickly cells and there is accumulation of glycogen. Morphologically they are not spinous and biochemically they do not keratinize. Rarely they contain keratohyaline granule and sparsely distributed intermediate keratin filament. The cells are attached by desmosomes and the cell surfaces are more closely apposed.
- c. *The superficial cell layer*—The nonkeratinized epithelium is devoid of stratum granulosum and stratum corneum. The superficial cells are large, flattened. They contain loosely arranged tonofilament, nuclei and few cell organelles. They are not dehydrated. So the surface is flexible and tolerant of both compression and distention.

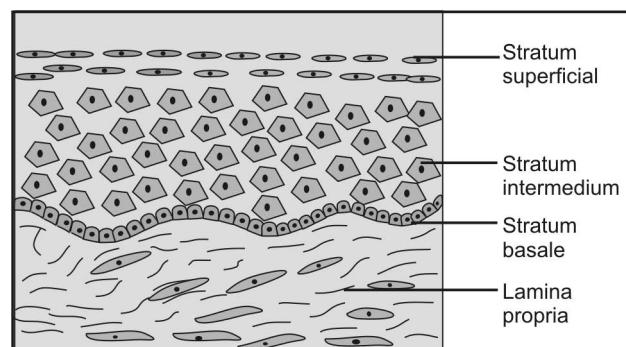


Fig. 11.6: Histology of non-keratinized oral epithelium

Table 11.2: Differences between masticatory and lining mucosa

	<i>Masticatory mucosa</i>	<i>Lining mucosa</i>
Site	Gingiva, hard palate, dorsum of tongue.	Lips, cheeks, soft palate, floor of the mouth, ventral surface of tongue and vestibule.
Color	Light pink, modified by melanin pigment.	Red, modified by melanin pigment.
Surface	Stippled.	Smooth.
Elasticity	Tightly bound.	Elastic.
Stratum corneum or Stratum superficial	Extremely flattened, dehydrated cells, in which cell organelles, nuclei are lost. Cells filled only with packed fibrillar material; When pyknotic nuclei are retained, it is parakeratinization.	Slightly flattened nucleated cells with fewer organelles, dispersed filaments and glycogen.
Stratum granulosum or Stratum intermedium	Flattened cells with keratohyaline granule, tonofibril, Odland bodies.	Slightly flattened cells with dispersed tonofilaments and glycogen
Stratum spinosum	Large ovoid cells with prominent tonofibril bundles, Odland bodies in upper layers.	Large ovoid cells with dispersed tonofilament.
Stratum basale	Cuboidal or columnar cells containing bundles of tonofibrils and other cell organelles.	Cuboidal or columnar cells with sparse tonofibrils.

Nonkeratinocytes in the Oral Epithelium

Nonkeratinocyte cells in the oral epithelium do not contain large numbers of tonofilaments and desmosomes seen in epithelial keratinocytes and none participates in the process of maturation. They constitute 10% of the cell population in the oral epithelium.

They lack desmosomal attachment to adjacent cells and during histologic processings the cytoplasm shrinks around the nucleus to produce the clear halo. So they are also termed as clear cells. They are named as 1. Melanocyte. 2. Langerhans' cell. 3. Merkel's cells. 4. Lymphocyte.

Table 11.3: Characteristics of non-keratinocytes in oral epithelium

<i>Cell type</i>	<i>Origin</i>	<i>Level in epithelium</i>	<i>Specific staining reaction</i>	<i>Ultra structure</i>	<i>Function</i>
Melanocytes	Neural crest cells.	Basal	Dopa oxidase Tyrosinase, silver stain	Dendritic, no desmosomes or tonofilaments, premelanosomes and melanosomes are present.	Synthesis of melanin pigment granules (melanosome) and transfer to surrounding keratinocytes.

Contd...

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Cell type	Origin	Level in epithelium	Specific staining reaction	Ultra structure	Function
Langerhans' cells	Bone marrow	Predominantly suprabasal	Hematoxylin and eosin stain, ATPase, cell surface antigen markers	Dendritic, no desmosomes or tonofilament, Langerhans' granule present	Act as part of the immune system as antigen presenting cells.
Merkel's cells	Neural crest cell	Basal	PAS stain	Non dendrite, sparse desmosome and tonofilament, electron dense vesicles and associated nerve axon	Tactile sensory cell
Lymphocyte	Bone marrow, lymphnode, spleen	Variable	Cell surface antigen marker (OKT-3)	Large circular nucleus, scant cytoplasm. No desmosome, tonofilament	Associated with inflammatory response in oral mucosa.

Junction of the Epithelium and Lamina Propria

The interface between the epithelium and connective tissue is usually corrugated. The upward projection of connective tissue is called connective tissue papillae (Fig.11.7A and B) which interdigitate with epithelial ridges or pegs, sometimes called rete ridges. The epithelium does not contain blood vessels and connective tissue papillae carry blood vessels and nerves.

The interlocking arrangement of the connective tissue papillae and the epithelial ridges increases the area of contact between the lamina propria and epithelium. This additional area facilitates exchange of material between the epithelium and the blood vessels in the connective tissue and also serve to strengthen the attachment to the connective tissue.

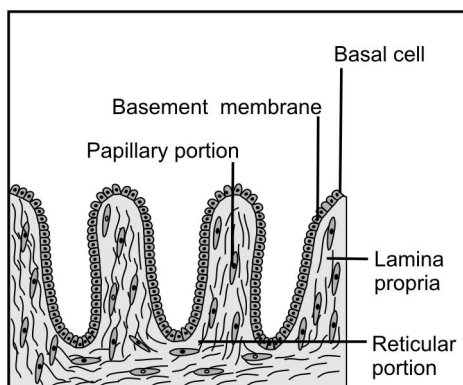


Fig. 11.7A: Junction of epithelium and lamina propria

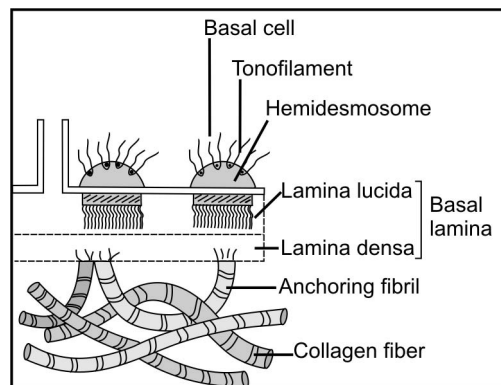


Fig. 11.7B: Junction of epithelium and lamina propria

Light microscopically, in a hematoxylin and eosin stained section, the interface between epithelium and connective tissue appears as a structureless layer about 1-2µm micrometer thick and it is known as basement membrane.

This zone stains positively with periodic acid schiff as it contains neutral mucopolysaccharide. It also contains fine argyrophilic reticular fiber.

Electron microscopically the basement membrane is known as basal lamina. It has two parts—

Lamina lucida—It is clear zone adjacent to epithelium and epithelial in origin. It is 45 nm wide. Basal cells are attached to lamina lucida by hemidesmosomes. Fine filaments termed anchoring filaments traverse lamina lucida opposite to hemidesmosome. Lamina lucida contains glycoprotein.

Lamina densa—It is a finely granular or filamentous material about 50 nm thick and placed below lamina lucida and it is connective tissue in origin. Inserted into lamina densa are small loops of finely banded fibrils called anchoring fibrils. Collagen fibrils run through these loops and are thus interlocked with the lamina densa to form a flexible attachment. It contains laminin and type IV collagen. Anchoring fibrils consist of type VII collagen and collagen that runs through the loops of anchoring fibrils is type I and type III collagen.

Lamina propria—The connective tissue supporting the oral epithelium is termed lamina propria. It has-

- a. Superficial papillary layer (associated with the epithelial ridges)
- b. Deeper reticular layer (which lies between the papillary layer and the underlying structure) [The term reticular means net like and refers to the arrangement of the collagen fibers].

The lamina propria consists of the cells, blood vessels, neural elements, and fibers (collagen and elastic) embedded in an amorphous ground substance (containing proteoglycans and glycoproteins).

Table 11.4: Cell types in lamina propria of oral mucosa

<i>Cell type</i>	<i>Morphology</i>	<i>Function</i>	<i>Distribution</i>
Fibroblast	Stellate or elongated with abundant rough endoplasmic reticulum.	Secretion of collagen fiber and ground substance.	Throughout lamina propria.
Histiocyte	Spindle-shaped or stellate, often dark-staining nucleus, many lysosomal vesicle.	Precursor of functional macrophage.	Throughout lamina propria.
Macrophage	Round with pale staining nucleus, contains lysosomes and phagocytic vesicles.	Phagocytosis, including antigen processing.	Areas of chronic inflammation.
Monocyte	Round with dark-staining kidney-shaped nucleus.	Phagocytic cell.	Areas of inflammation.
Mast cell	Round or oval with basophilic granules, staining metachromatically.	Secretion of histamine, heparin, serotonin.	Throughout lamina propria, often sub-epithelial.
Polymorpho nuclear leukocyte	Round with lobulated nucleus.	Phagocytosis.	Site of acute inflammation.

Contd...

Contd...

<i>Cell type</i>	<i>Morphology</i>	<i>Function</i>	<i>Distribution</i>
Lymphocyte	Round with dark staining nucleus.	Participate in humoral or cell mediated immune response.	Site of inflammation.
Plasma cells	Cartwheel nucleus, profuse rough endoplasmic reticulum	Synthesis of immunoglobulin	Area of chronic inflammation
Endothelial cell	Associated with basal lamina.	Lining of blood and lymphatic.	Lining vascular channels of lamina propria.

Submucosa—In many regions (e.g. cheeks, lips, parts of the hard palate) a layer of loose fatty or glandular connective tissue containing the major blood vessels and nerves separates the oral mucosa from underlying bone or muscle. This region is known as submucosa of oral cavity. Its composition determines the flexibility of the attachment of oral mucosa to the underlying structures.

Mucoperiosteum—In the regions of gingiva and parts of hard palate, oral mucosa is attached directly to the periosteum of underlying bone, with no intervening submucosa. This is called mucoperiosteum which provides a firm inelastic attachment.

[A common feature of all epithelial cells is that they contain keratin intermediate filaments which resembles tonofilaments and are 7 - 11 nm in width.

Similarly connective tissue contain vimentin, muscle tissue contain desmin and nerve cells contain neural filaments].

Structure of Mucosa in Different Regions of the Oral Cavity

In different parts of the mouth, the mucosa has different roles and experiences different degrees and types of stress during mastication, speech and facial expression. As a consequence, the structure of oral mucosa varies in terms of the thickness of the epithelium, the degree of keratinization, the complexity of the connective tissue-epithelium interface, the composition of lamina propria and the presence or absence of submucosa.

Keratinized Area

- A. Masticatory mucosa 1. Hard palate 2. Gingiva.
- B. Vermilion zone of lip.

Masticatory Mucosa

The masticatory mucosa is keratinized, e.g. hard palate and gingiva.

The common features—

- a. The pedicles (serrations in cells to strengthen the attachment to the connective tissue)
- b. The increase in number and length of the desmosomes
- c. The density of the tonofilaments
- d. Complimentary grooves and ridges all appear to be adaptations of keratinizing epithelium to resist forces and to bind the epithelium to the connective tissue.

Hard palate and gingiva have similarities in thickness, keratinization and lamina propria but they have differences in submucosa.

Hard Palate—(Fig. 11.8)

The following zones in the hard palate can be distinguished—

- a. Gingival region—adjacent to teeth.
- b. Mid palatine raphe—from incisive or palatine papilla posteriorly.
- c. Anterolateral fatty zone between the raphe and gingiva.
- d. Posterolateral glandular area between raphe and gingiva.

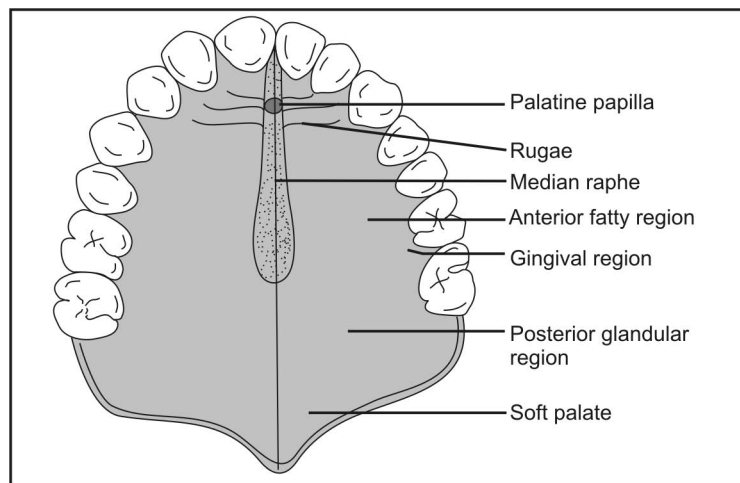


Fig. 11.8: Hard palate

The mucosa of the hard palate is thick, orthokeratinized or parakeratinized, stratified squamous epithelium, long connective tissue papillae, thick dense collagenous tissue, moderate vascular supply with short capillary loops.

There is no submucosa in the region of mid palatine raphe and attached gingiva and the lamina propria binds down directly to bone. (mucoperiosteum).

Between the raphe and gingiva, the palate contains submucosa with neurovascular bundles, adipose tissue (predominantly anteriorly), minor mucous glands (predominantly posteriorly) (Fig.11.9).

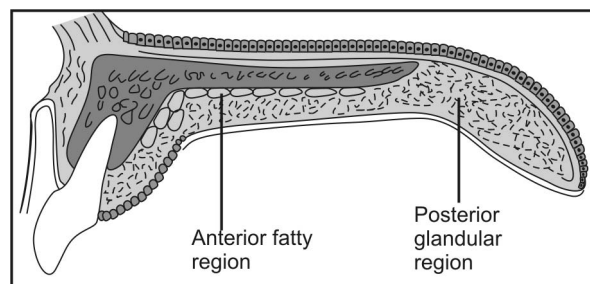


Fig. 11.9: Diagram of sagittal section through palate

The nasal surface of hard palate is lined by a respiratory mucosa of ciliated columnar epithelium.

Incisive papilla—The oral incisive (palatine) papilla is formed of dense connective tissue covered by keratinized epithelium. It contains the oral parts of the vestigial nasopalatine ducts. They are blind ducts of varying length lined by simple or pseudostratified columnar epithelium, rich in goblet cell.

Palatine rugae—They are irregular, asymmetric, ridges of mucosa extending laterally from the incisive papilla and the anterior part of the raphe. Their core is made of a dense connective tissue layer with fine interwoven fibers.

Epithelial pearls—In the midline, especially in the region of the incisive papilla, concentrically arranged keratinized epithelial cells are found in the lamina propria. They are remnants of the epithelium formed in the line of fusion between the palatine processes.

Gingiva—(Fig.11.10)

Gingiva is that part of oral mucosa which surrounds the tooth and covers the alveolus.

It can be divided into—

- a. *Free gingiva*—About 1 to 1.5 mm of coronal part of gingiva is loosely attached to the tooth and is called free gingiva.

The potential space between tooth and free gingiva is called gingival sulcus or gingival crevice. The region apical to this, where the gingiva is bound to the underlying tooth, is the junctional epithelium.

From facial or lingual aspects the margins of free gingiva appear as a wavy line and is known as marginal gingiva.

The free gingiva in the interproximal area is known as Papillary gingiva or interproximal gingiva.

- b. *Attached gingiva*—The gingiva apical to the free gingiva is firmly attached to the underlying structures by gingival fibers of periodontal ligament and is called attached gingiva. The surface of attached gingiva has a stippled or pitted appearance. This is due to high connective tissue papillae elevating the epithelium.

The junction of free and attached gingiva produces a scalloped depressed line known as free gingival groove, which runs parallel to the margin of gingiva.

The attached gingiva is continuous with alveolar mucosa. This border is scalloped and is called muco-gingival line. On the palatal surface of the maxillary teeth there is no alveolar

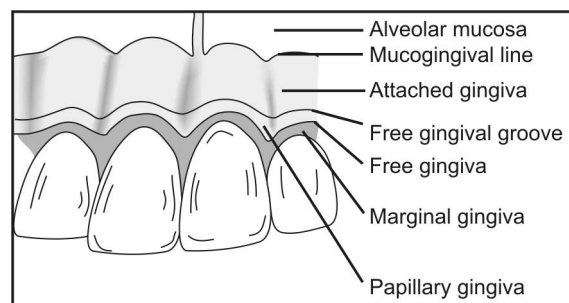


Fig. 11.10: Diagram of surface characteristics of gingiva

mucosa. Here, the attached gingiva merges with the palatal mucosa, with no clearly demarcated boundary.

The attached gingiva may be slightly depressed between adjacent teeth corresponding to the depression on the alveolar process between the eminences of the sockets. These depressions on the gingiva are called interdental folds.

The interdental papilla is that part of the gingiva that fills the space between two adjacent teeth. When viewed from oral or vestibular aspect, the surface of the interdental papilla is triangular. In a three dimensional view the interdental papilla of the posterior teeth is tent shaped, whereas it is pyramidal between anterior teeth.

Col—It is the concave area of interdental papilla between the higher oral and vestibular corners and it fits below the contact point. The col is covered by thin nonkeratinized epithelium and is more vulnerable to periodontal disease.

The gingiva is covered by stratified squamous epithelium, which may be non-keratinized or orthokeratinized but predominantly parakeratinized. The epithelium covers a dense lamina propria with long, slender papillae, dense collagenous connective tissue which is not highly vascular but contains long capillary loops with numerous anastomosis. There is no distinct layer of submucosa and mucosa is firmly attached by collagen fibers to cementum and periosteum of alveolar process.

Vermilion Zone of Lip

The transitional zone between the skin of the lip and the mucous membrane of the lip is the red zone, or the vermillion border. It is found only in humans. It is covered by a moderately thick, keratinized epithelium, numerous densely arranged long papillae of the lamina propria, reaching deep into the epithelium and carrying large capillary loops close to the surface. As the blood vessels are visible through the thin, translucent epithelium, the zone appears red. Some sebaceous glands are present in submucosa and it is firmly attached to underlying muscle.

Non-Keratinized Areas

- a. Lining mucosa .
- b. Specialized mucosa.

Lining Mucosa

Labial mucosa and buccal mucosa (Lip and Cheek)—These are covered by thick, non-keratinized stratified squamous epithelium. The lamina propria shows short and comparatively broad papillae, the basement membrane zone is wavy. There is dense fibrous connective tissue containing collagen and some elastic fibers; rich vascular supply giving off anastomosing capillary loops into papillae. Mucosa is firmly attached to underlying muscle by collagen and elastin (buccal mucosa to buccinator muscle and labial mucosa to orbicularis oris). There are adipose tissue, minor salivary glands and sometimes ectopic sebaceous gland (Fordyce's spot).

Vestibular Fornix and Alveolar Mucosa—

The labial and buccal mucosa are reflected from vestibular fornix to the alveolar mucosa covering bone. They are covered by thin, non-keratinized stratified squamous epithelium. Connective tissue papillae are short and absent. Connective tissue contains many elastic fibers, capillary

loops close to surface and salivary gland. In the fornix (vestibule), the mucosa is loosely connected to underlying structures, allowing the necessary movements of the lips and cheeks. The alveolar mucosa is also loosely attached to underlying periosteum.

Ventral Surface of the Tongue, Floor of the Mouth—

Epithelium—These areas are covered by thin, non-keratinized stratified squamous epithelium.

Lamina propria—

- a. *Ventral surface of tongue*—Lamina propria contains thin, numerous short papillae, some elastic fibers, few minor salivary glands, capillary network in subpapillary layer, reticular layer is relatively avascular.
- b. *Floor of the mouth*—Lamina propria contains short papillae, elastic fiber and extensive vascular supply with short anastomosing capillary loops.

Submucosa—

- a. *Ventral surface of tongue*—submucosa binds the mucous membrane tightly to the connective tissue surrounding the bundles of the muscles of the tongue.
- b. *Floor of the mouth*—Submucosa contains adipose tissue and it is loosely attached to the underlying structures to allow the free movement of tongue.

Soft Palate

The covering epithelium is non-keratinized stratified squamous epithelium. The papillae of connective tissue are few and short and shows a distinct layer of elastic fibers separating from submucosa. It is highly vascular with well-developed capillary network. The submucosa is loose, diffuse, containing numerous salivary gland and taste buds.

Specialized Mucosa

Dorsal Surface of Tongue

The dorsum of tongue (Fig.11.11) is divided grossly into an anterior two-third (body of tongue) and a posterior one-third (base of tongue) by a V-shaped indistinct groove, the sulcus terminalis. The angle of the V shows a depression called foramen cecum. The anterior part is covered by a keratinized stratified squamous epithelium with four types of papillae. They are filiform, fungiform, foliate and circumvallate papillae.

The posterior one-third of tongue is non-keratinized and studded with small lymphatic nodule (or follicles).

Filiform papillae-(Fig.11.12)—They are about 2.5 mm. long, conical in shape (flame shaped) and arranged in rows parallel to the sulcus terminalis. The epithelial covering of these papillae are thick. Each papilla consists of a loose connective tissue core covered by a keratinized stratified squamous epithelium with many secondary papillae. They do not contain taste buds.

Fungiform papillae-(Fig.11.13)—They are isolated, short, flat topped, elevated, reddish, dome shaped (mushroom shaped), 2 mm long and 1 mm wide. They are disposed among the filiform papillae but are much less in number compared to filiform papillae. They are covered by a relatively thin, non-keratinized epithelium. The color is derived from a rich capillary network visible through the relatively thin epithelium. They bear few taste buds.

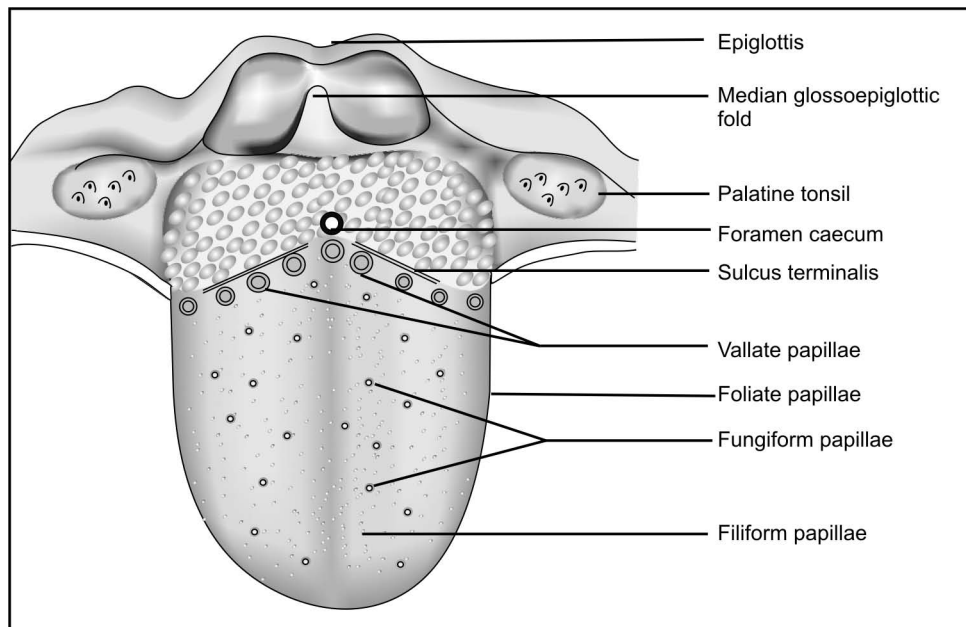


Fig. 11.11: Diagram of tongue

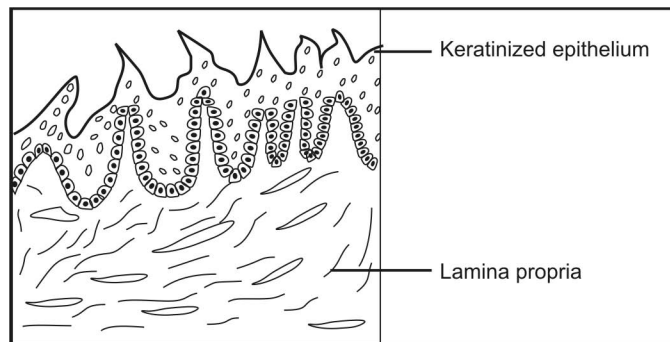


Fig. 11.12: Filiform papillae

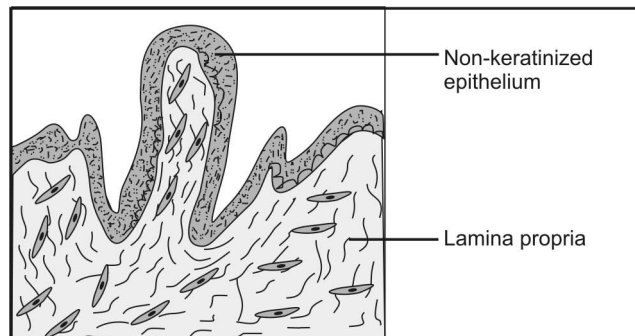


Fig. 11.13: Fungiform papillae

Foliate papillae—They are seen as four to eight parallel mucosal folds at the bilateral lateral borders near the posterior part of the body of the tongue. They are well developed at birth but become rudimentary during adult life. They bear taste buds and excretory ducts from Von Ebner glands.

Circumvallate papillae-(Fig.11.14)—These are largest of the papillae, 10-12 in number and are situated in front of sulcus terminalis. They are mushroom shaped (resemble inverted truncated cone) submerged circular structures, 1 mm high and 2.5 mm wide, surrounded on all sides by a trench or crypt. These papillae have a connective tissue core that is covered on the superior surface by a keratinized epithelium. The epithelium covering the lateral walls is nonkeratinized and contains multiple taste buds. Small serous glands (of Von Ebner) empty into the base of the trench.

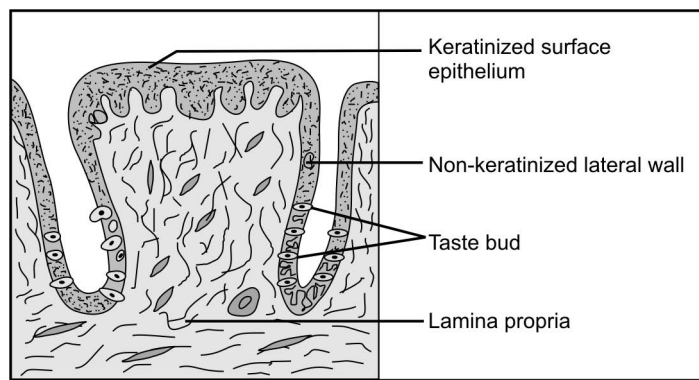


Fig. 11.14: Circumvallate papillae

Taste buds-(Fig.11.15)—These are chemoreceptive organs responsible for taste is located particularly within the epithelium around the walls of the circumvallate papillae, on the upper surface of fungiform papillae in the lateral wall of foliate papillae, and in the mucosa of the soft palate.

Histologically taste buds are a small ovoid or barrel-shaped intraepithelial organs about 80 μm high and 40 μm thick. They extend from the basal lamina to the surface of the epithelium and are separated from underlying connective tissue by basal lamina. Their outer surface is almost covered by flat epithelial cells, which surround a small opening, the taste pore.

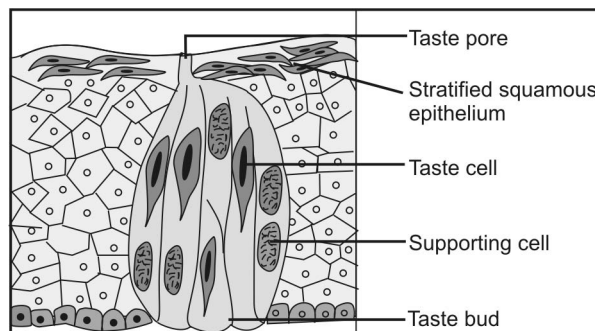


Fig. 11.15: Taste bud

They consist of two types of cells—

- a. Supporting cells (sustentacular cells)—The cells are wide with round, faintly stained nucleus. They are without hair and are found in the peripheral part of the organ.
- b. Taste cells—They are long, fusiform with dark-staining centrally located oval nuclei. The cells occupy the core of the taste organ. The ends of the cells facing the taste pore bear hairs which are modified microvilli. The hairs project into the lumen of the pore. The top of the taste canal is open to allow the entrance of fluids.

Table 11.5: Distribution of primary taste sensations

<i>Taste</i>	<i>Site</i>	<i>Name of papillae</i>	<i>Nerve</i>
Sweet	Tip of tongue	Fungiform papillae	Chorda tympani
Salty	Lateral border of tongue	Fungiform papillae	Chorda tympani
Bitter	Posterior part of tongue	Circumvallate papillae	Glossopharyngeal nerve
Sour	Lateral border and posterior part of tongue	Foliate papillae	Glossopharyngeal nerve

[Taste stimuli are probably generated by the adsorption of molecules on to membrane receptors on the surface of the taste bud cells, which activates a signaling cascade mediated by membrane associated proteins such as transducin and gustducin. The change in membrane polarization that follows, stimulates release of transmitter substances, which, in turn, stimulate unmyelinated afferent fibers of the glossopharyngeal nerve, which surround the lower half of the taste cells].

Gingival Sulcus and Dentogingival Junction

Gingival sulcus (Fig.11.16)—The gingival sulcus is the shallow crevice or space around the tooth bounded by the surface of the tooth on one side and sulcular epithelium on the other. The

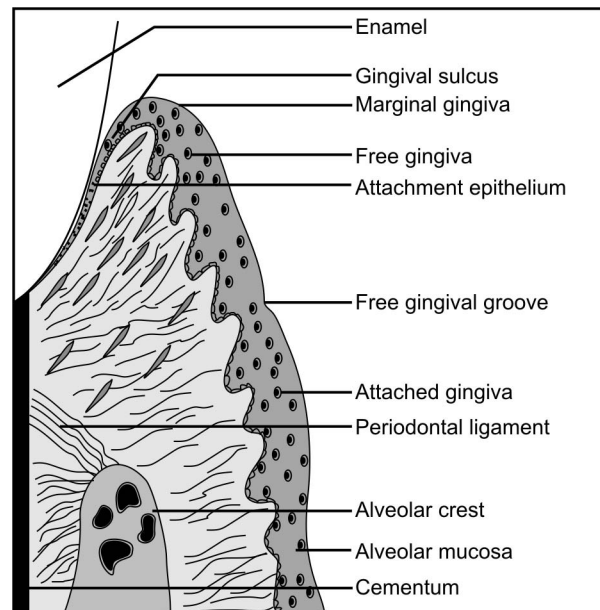


Fig. 11.16: Gingival sulcus and junctional epithelium

inferior boundary of the gingival sulcus is the attachment of the junctional epithelium and the coronal extent is the epithelium lining the free margin of the gingiva on the other.

In clinically healthy gingiva in human's, the depth of the sulcus varies from 0 to 6 mm.

The sulcular epithelium lines the gingival sulcus. It is a thin, non-keratinized, stratified squamous epithelium without rete pegs and extends from the coronal limit of the junctional epithelium to the crest of gingival margin. It acts as a semipermeable membrane through which injurious bacterial products pass into gingiva and through which tissue fluid from gingiva seeps into sulcus.

Sulcular fluid—The gingival sulcus contains a fluid that seeps into it from the gingival connective tissue through the thin sulcular epithelium. The gingival fluid is believed to

1. Cleanse material from sulcus,
2. Contain plasma protein that may improve adhesion of the epithelium to the tooth,
3. Possess antimicrobial properties,
4. Exert antibody activity in the defense of the gingiva.

Dentogingival Junction—(Junctional Epithelium)

The junctional epithelium consists of a collar-like band of nonkeratinizing stratified squamous epithelium. It is three to four layers thick in early life, but the number of layers increases with age to 10 or even 20. These cells can be grouped in two strata, basal and suprabasal.

Development of Gingival Sulcus and Junctional Epithelium (Fig. 11.17A and B)

After completion of enamel formation, the ameloblasts leave a thin membrane on the surface of the enamel, the primary enamel cuticle. It is connected to interprismatic enamel.

Then four layers of enamel organ are reduced to few layers of flat cuboidal cells known as reduced enamel epithelium. It covers entire enamel upto cementoenamel junction and is attached to the primary enamel cuticle.

At the time of eruption of tooth, the reduced enamel epithelium fuses with the oral epithelium. The epithelium surrounding the tip of the crown degenerates and the crown emerges through the perforation into the oral cavity. The reduced enamel epithelium attached to enamel is known as primary attachment epithelium which is continuous with oral epithelium. The remnant of the primary enamel cuticle is known as Nasmyth's membrane.

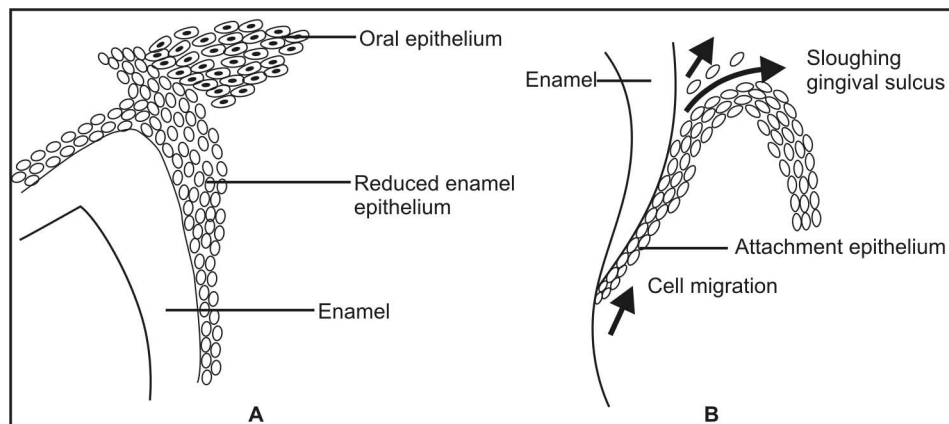


Fig. 11.17A and B: Development of gingival sulcus and junctional epithelium

The shallow groove between gingiva and tooth surface is gingival sulcus. It is bounded by the attachment epithelium at its base and by the gingival margin laterally.

Gradually the tooth emerges into plane of occlusion and the reduced enamel epithelium (primary attachment epithelium) is totally replaced by oral epithelium. It is now known as secondary attachment epithelium.

The attachment epithelium is attached to tooth by a basal lamina and hemidesmosomes. It is submicroscopic, 40 nm wide and is known as epithelial attachment.

Migration of Attachment Epithelium

The site and extent of attachment epithelium is not static but is changing. With advancing age there is an apical migration of the attachment and consequently an increase in the height of the clinical crown by passive eruption. The migration can be described in four stages—

1. The lower end of the attachment epithelium is at the cemento enamel junction and the bottom of the crevice is on the enamel (Fig.11.18A).
2. The attachment epithelium is partly on the enamel and partly on the cementum. (Fig.11.18B). The bottom of the crevice is on enamel.
3. The attachment epithelium lies entirely on cementum and the bottom of the crevice at the cemento enamel junction (Fig.11.18C).
4. The attachment epithelium and the bottom of the crevice are on the cementum (Fig.11.18D).

Deepening of Sulcus (Pocket Formation)

The gingival sulcus deepens as a result of separation of junctional epithelium from actively erupting tooth. The more shallow a sulcus, the more likely that the gingival margin is not inflamed. Lymphocytes and plasma cells in the connective tissue at the bottom of the gingival sulcus constitute a barrier against the invasion of bacteria and the penetration of toxins.

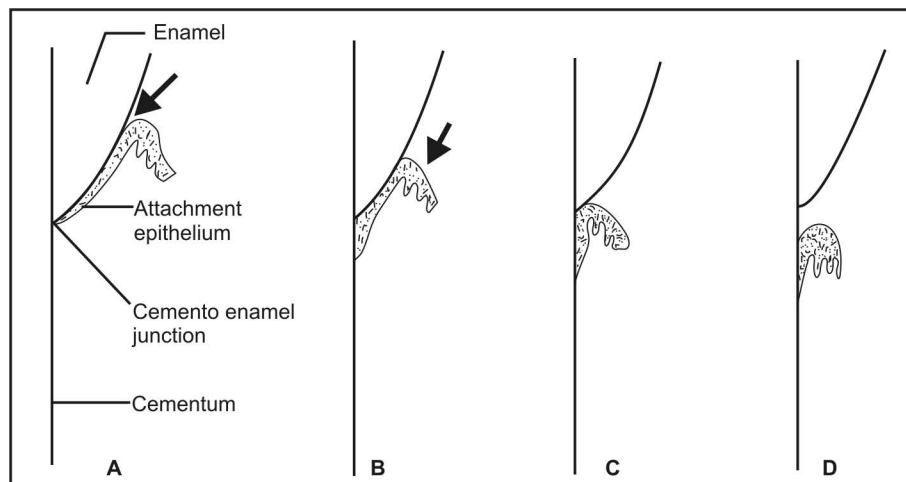


Fig. 11.18A to D: Migration of attachment epithelium

Age Changes

1. In elderly person the oral mucosa becomes smooth, dry (due to atrophy of salivary gland), thin (atrophic) and friable. These features lead to the symptoms of burning sensations and abnormal taste.
2. Development of nodular varicose veins on the undersurface of tongue.
3. Reduction in number of filiform papillae.
4. Histologically the epithelium becomes thin, epithelium connective tissue interface becomes flattened, Langerhans' cells become fewer (decline in cell mediated immunity). Lamina propria shows decreased cellularity, increased collagen, marked atrophy of salivary glands.

Clinical Consideration

1. Oral mucous membrane is clinically very important. It reflects signs of a large volume of systemic diseases. Nutrition deficiencies, skin diseases, infectious diseases, blood disorders are manifested orally.
2. Deepening of gingival sulcus leads to periodontal diseases.
3. Use of pan, betel nut, tobacco may cause precancer (leukoplakia, submucous fibrosis or cancerous change of oral mucosa).
4. In denture bearing areas mucosa must be firm and moist.
5. In old age thin and dry oral mucosa leads to severe burning sensation.

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Eruption and Shedding of Tooth

Eruption-(Latin Erumpere, to Break Out)

Eruption is defined as axial or occlusal movement of the tooth from its developmental position within the jaw to its functional position in the occlusal plane.

For the teeth to become functional, considerable movement is required to bring them into occlusal plane. The physiologic movements made by teeth are complex and may be described as—

1. *Preeruptive tooth movement*—Made by the deciduous and permanent tooth germs within tissues of the jaw before they begin to erupt. Pre-eruptive stage extends from initiation of tooth germ to beginning of root formation.
2. *Eruptive tooth movement*—Made by a tooth to move from its position within the bone of the jaw to its functional position in occlusion. The eruptive stage starts from the beginning of root formation and extends till the tooth reaches the occlusal plane.
3. *Post eruptive tooth movement*—Maintaining the position of the erupted tooth in occlusion while the jaws continue to grow and compensate for occlusal and proximal tooth wear. Posteruptive stage starts from the tooth reaches the occlusal plane and extends till the tooth is lost.

Superimposed on these movements is the replacement of entire deciduous dentition by the permanent.

The movement of tooth in relation to bone is called active eruption. The exposure of the erupting tooth by recession of gingiva and peeling of the epithelial attachment is called passive eruption.

Preeruptive Tooth Movement

When the deciduous tooth germs first differentiate, they are extremely small, and there is a good deal of space for them in the developing jaw. Because they grow rapidly, they become crowded. This crowding is gradually alleviated by a lengthening of the infant jaws, which provides room for the second deciduous molars to drift backward and the anterior teeth to drift forward. At the same time the tooth germs also move outward as the jaws increase in width, and upward (downward in the upper jaw) as the jaws increase in height.

Permanent teeth with deciduous predecessors also undergo complex movements before they reach the position from which they will erupt. The permanent incisors and canines first develop lingual to the deciduous tooth germs at the level of their occlusal surfaces and in the

same bony crypt (Fig.12.1). As their deciduous predecessors erupt they move to a more apical position and occupy their own bony crypts (Fig.12.2). Permanent premolars begin their development lingual to their predecessors at the level of their occlusal surfaces and in the same bony crypt. They also shift so that they are eventually situated in their own crypts beneath the divergent roots of the deciduous molars (Fig.12.3).

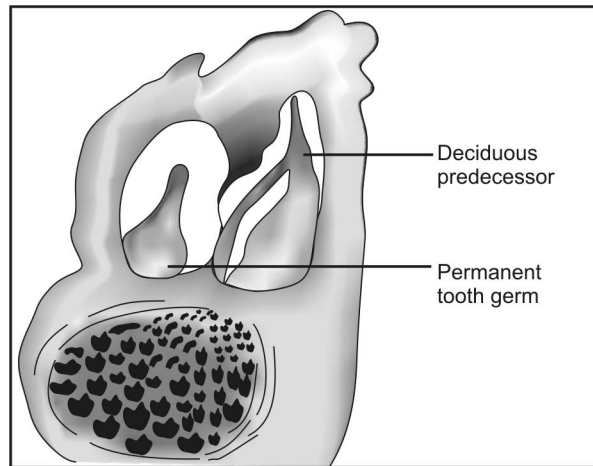


Fig. 12.1: Relationship between developing permanent incisor with deciduous predecessor

The permanent molars, which have no deciduous predecessors, also move considerably from the site of their initial differentiation. For example, the upper permanent molars, which develop in the tuberosity of the maxilla, (Fig.12.4) at first have their occlusal surfaces facing distally and swing around only when the maxilla has grown sufficiently to provide the necessary space. Similarly, mandibular molars develop with their occlusal surfaces inclined mesially and only become upright as room becomes available. All these movements are linked to jaw growth and may be considered as movements positioning the tooth and its crypt within the jaws preparatory to tooth eruption.

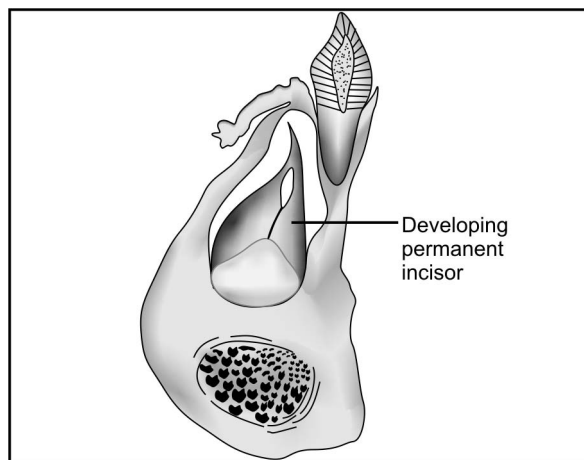


Fig. 12.2: Apical movement of developing permanent incisor

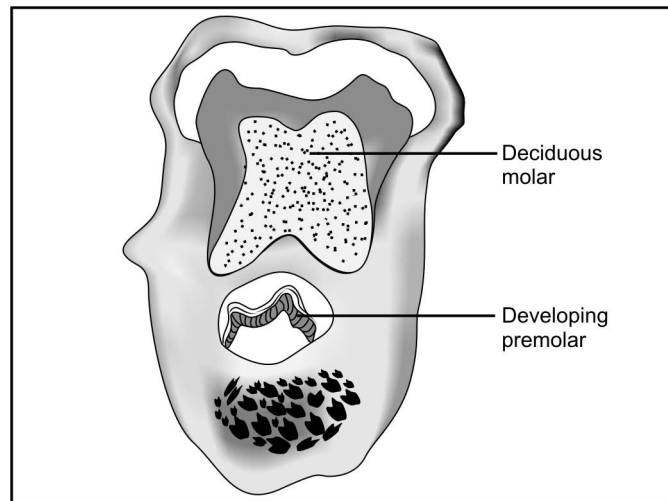


Fig. 12.3: Developing premolar beneath the divergent roots of deciduous molars

Eruptive Tooth Movement

During the phase of eruptive tooth movement the tooth moves from its position within the bone of the jaw to its functional position in occlusion, and the principal direction of movement is occlusal or axial (movement along the long axis of tooth). However, it is important to recognize that jaw growth is normally occurring while most teeth are erupting, so that movement in planes other than axial is superimposed on eruptive movement.

Posteruptive Tooth Movement

Posteruptive tooth movements are those that—

1. maintain the position of the erupted tooth while the jaw continues to grow;
2. compensate for occlusal and proximal wear. The former movement, like eruptive movement, occurs principally in an axial direction to keep pace with the increase in height of the jaws. It involves both the tooth and its socket and ceases when jaw growth is completed. The

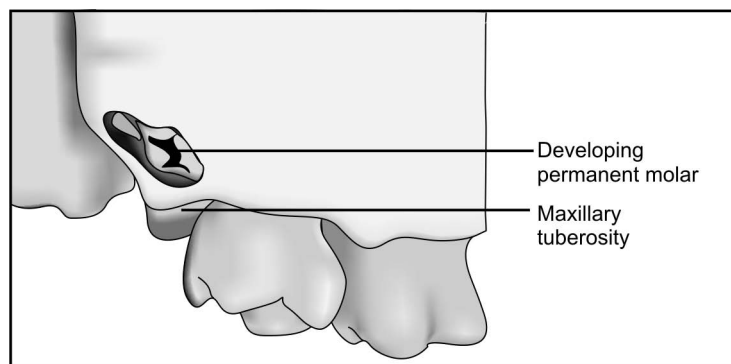


Fig. 12.4: Developing permanent molar in maxillary tuberosity

movements compensating for occlusal and proximal wear continue throughout life and consist of axial and mesial migration, respectively.

Histology of Tooth Movement

Preeruptive Phase

During the preeruptive phase, positioning of the developing tooth within the growing jaws is achieved in two ways—

1. There is a total bodily movement of the germ.
2. There is its eccentric growth which means that one part of the developing tooth germ remains stationary while the remainder continues to grow, leading to a shift in its center. This type of growth explains how the deciduous incisors maintain their superficial position as the jaws grow in height.

Histologically, preeruptive tooth movement is reflected by bone remodeling at the periphery of the dental follicle, bringing about bone remodeling of the crypt wall. Thus during bodily movement of the tooth, osteoclastic bone resorption occurs on the surface of the crypt wall in advance of the moving tooth while bone deposition occurs on the crypt wall behind it. During eccentric movement bone resorption is seen on the surface of the crypt that faces the growing tooth germ.

Eruptive phase—During the eruptive phase of physiologic tooth movement, significant developmental changes occur, including the formation of the roots, periodontal ligament, and dentogingival junction of the tooth.

Root formation is initiated by proliferation of Hertwig's epithelial root sheath. The forming root first grows toward the floor of the bony crypt and, as a result, there is resorption of bone in this location to provide room for the advancing root tip. However, with the onset of eruptive tooth movement space is created for the forming root, and resorption no longer occurs on the floor of the crypt. Indeed, in some instances the distance moved by the tooth outstrips the rate of root formation and bone deposition occurs on the crypt floor (Fig.12.5).

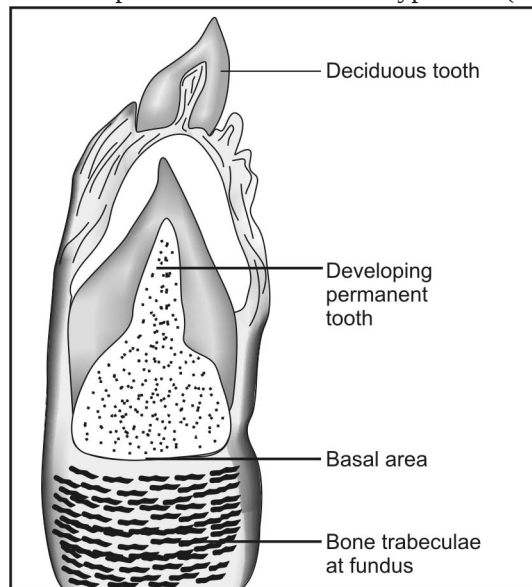


Fig. 12.5: Bone deposition on crypt floor

As the roots of the tooth form, important changes associated with the development of the supporting apparatus of the tooth occur in the dental follicle. There is bone deposition on the crypt wall, cement deposition on the newly formed root surface, and organization of a periodontal ligament from the dental follicle. These changes lag behind root formation.

There are number of important histologic features in the periodontal ligament that are important in explaining eruptive tooth movement—

1. Occurrence of cell-to-cell contacts of the adherens type between periodontal ligament fibroblasts.
2. Presence of contractile elements in ligament fibroblasts.
3. Occurrence of a structure called the fibronexus. This describes a morphologic relationship between intracellular microfilaments in the fibroblast, a corresponding increased density of fibroblast cell membrane, extracellular filaments, and fibronectin. Fibronectin is a sticky glycoprotein that sticks to a number of extracellular components, including collagen.
4. Active ingestion and degradation of old collagen fibrils by many of the fibroblasts of the ligament and the concurrent formation of new collagen fibrils. Thus the continual degradation and synthesis of collagen by fibroblasts permit remodeling of the principal fiber bundles of the periodontal ligament.

Significant changes occur within the tissues that cover the erupting tooth. There is a loss of the intervening connective tissue between the reduced enamel epithelium covering the crown of the tooth and the overlying oral epithelium. Then two epithelia proliferate and form a solid plug of cells in advance of the erupting tooth. The central cells of this epithelial mass degenerate and form an epithelium-lined canal through which the tooth erupts without any hemorrhage. This epithelial cell mass is also involved in the formation of the dentogingival junction.

Once the tooth has broken through the oral mucosa, it continues to erupt at the same rate until it reaches the occlusal plane and meet its antagonist. As further occlusal movement is restricted, additional root growth is accommodated by removal of bone on the socket floor.

Successional teeth possess an additional anatomic feature, the gubernacular canal and its contents, the gubernacular cord, which may have an influence on eruptive tooth movement. When the successional tooth germ first develops within the same crypt as its deciduous predecessor, bone surrounds both tooth germs but does not completely close over them. As the deciduous tooth erupts, the permanent tooth germ becomes situated apically and entirely enclosed by bone and except for a small canal that is filled with connective tissue and often contains epithelial remnants of the dental lamina. This connective tissue mass is termed the 'gubernacular cord' (Fig.12.6). and it may have a function in guiding the permanent tooth as it erupts.

Posteruptive phase—In the posteruptive phase the tooth makes movements primarily to accommodate the growth of the jaws. The principal movement is in an axial direction. It occurs most actively between the ages of 14 and 18 and is associated with condylar growth, which separates the jaws and teeth. Although bone deposition occurs at the alveolar crest and on the socket floor, this is not responsible for tooth movement. The same forces responsible for eruptive tooth movement achieve axial posteruptive movement with bone deposition occurring later.

There are also movements made to compensate for occlusal and proximal wear of the tooth. It is generally assumed that the continuous deposition of cement around the apices of the roots of teeth is sufficient to compensate for occlusal wear.

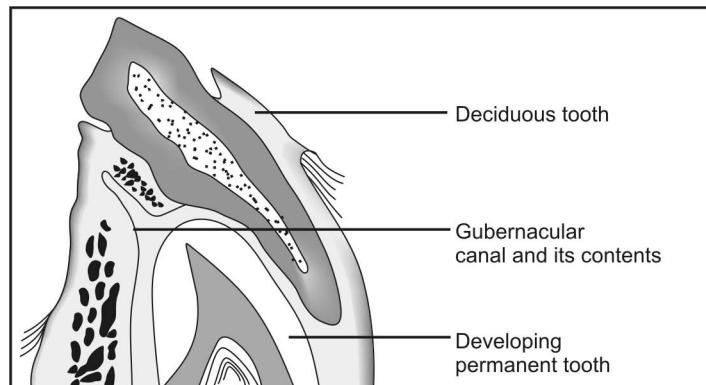


Fig. 12.6: Gubernacular cord

It is more likely that the forces causing tooth eruption are still available to bring about sufficient axial movement of the tooth to compensate for occlusal wear. The cement deposition that occurs is probably an infilling phenomenon.

Wear also takes place at the contact points between teeth, and to maintain tooth contact mesial or proximal drift takes place. Histologically this drift is seen as a selective deposition and resorption of bone on the socket walls by osteoblasts and osteoclasts respectively.

Mechanism of Eruption of Tooth

The mechanism that causes eruption of tooth is a combination of factors. They are (1) bone remodeling (2) root growth (3) vascular pressure (4) ligament traction.

Bone remodeling—Bone remodeling of the crypt wall is important to achieve tooth eruption, and in experiments where tooth germ is removed but the follicle is left in position, the eruptive pathway still forms in bone. Such experiments properly indicate dental follicle, (not bone) as the major determinant in tooth eruption.

Root growth—This theory states that pulp grows and pushes against the cushion hammock ligament which passes from one side of bony wall of the socket to the opposite wall. Recent work has shown that this hammock ligament does not extend across the socket, but only separates the pulp from the follicle. It is attached to root only and rootless teeth are seen to erupt also. These make this theory untenable (Fig.12.7).

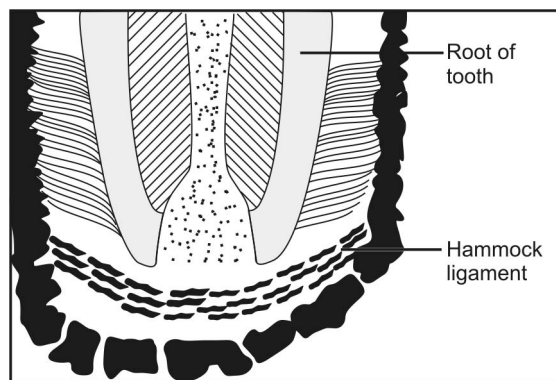


Fig. 12.7: Mechanism of eruption—root growth

Vascular pressure—It is known that teeth move in synchrony with the arterial pulse, so local volume changes can produce limited tooth movement. Ground substance can swell by up to 50% with the addition of water, and a differential pressure sufficient to cause tooth movement between the tissues below and above an erupting tooth has been reported in the dog. Again, whether such pressures are the prime movers of teeth is debatable because surgical excision of the root, and therefore the local vasculature, does not prevent tooth eruption.

Periodontal ligament traction—There is a good deal of evidence that the eruptive force resides in the dental follicle-periodontal ligament complex. The fibroblasts with contractile filaments are in contact with one another to permit summation of contractile forces, and exhibit fibronexus by which such forces can be transmitted to the collagen fiber bundles. These not only remodel but are also inclined at the correct angle to bring about eruptive movement. This angulation of the ligament fiber bundles is a prerequisite for tooth movement, and the orientation is believed to be established by the developing root.

The follicle, before it becomes periodontal ligament, also plays a role in tooth eruption, even though it may not provide the actual eruptive force.

In summary, eruptive movement is brought about by a combination of events involving a force initiated by the fibroblast. This force is transmitted to the extracellular compartment via fibronexus and to collagen fiber bundles, which, aligned in an appropriate inclination brought about by root formation, bring about tooth movement.

In posteruptive tooth movement the mechanisms for moving the tooth axially during eruption are most likely also used to compensate for occlusal wear. Mesial, or proximal, drift involves a combination of two separate forces resulting from occlusal contact of teeth and contraction of the transseptal ligaments between teeth.

Running between teeth across the alveolar process is the transseptal ligament, and there is evidence that this ligament has a key role in maintaining tooth position.

Mesial drift is achieved by contraction of transseptal fibers and enhanced by occlusal forces.

The teeth erupt into oral cavity at different times. A summary of this eruption sequence is as follows—(Fig.12.8).

Deciduous					Permanent							
10	6	8	4	2	4	6	12	8	9	2	14	16
9	5	7	3	1	3	5	7	10	11	1	13	15
M ₂	M ₁	C	I ₂	I ₁	I ₁	I ₂	C	PM ₁	PM ₂	M ₁	M ₂	M ₃

Fig. 12.8: Sequence of eruption of teeth

Primary Dentition**Emergence into oral cavity***Maxillary*

Central incisor	7 months
Lateral incisor	9 months
Canine	18 months
First molar	14 months
Second molar	24 months

Mandibular

Central incisor	6 months
Lateral incisor	7 months
Canine	16 months
First molar	12 months
Second molar	20 months

Permanent Dentition*Maxillary*

Central incisor	7-8 yrs
Lateral incisor	8-9 yrs
Canine	11-12 yrs
First premolar	10-12 yrs
Second premolar	10-12 yrs
First molar	6-7 yrs
Second molar	12-13 yrs
Third molar	18-25 yrs

Mandibular

Central incisor	6-7 yrs
Lateral incisor	7-8 yrs
Canine	9-10 yrs
First premolar	10-12 yrs
Second premolar	11-12 yrs
First molar	6-7 yrs
Second molar	11-13 yrs
Third molar	18-25 yrs

Shedding of the Deciduous Teeth

Definition—The physiologic process resulting in the elimination of the deciduous dentition is called shedding or exfoliation.

Pattern of Shedding

The shedding of deciduous teeth is the result of progressive resorption of the roots of teeth and their supporting tissue, the periodontal ligament. The removal of the dental hard tissues, is

accomplished by multinuclear odontoclasts (Fig.12.9). In general, the pressure generated by the growing and erupting permanent tooth dictates the pattern of deciduous tooth resorption. At first this pressure is directed against the root surface of the deciduous tooth itself. Because of the developmental position of the permanent incisor and canine tooth germs and their subsequent physiologic movement in an occlusal and vestibular direction, resorption of the roots of the deciduous incisors and canines begins on their lingual surfaces. Later these developing tooth germs occupy a position directly apical to the deciduous tooth, which permits them to erupt in the position formerly occupied by the deciduous tooth. Frequently, however, and especially in the case of the permanent mandibular incisors, this apical positioning of the tooth germs does not occur and the permanent tooth erupts lingual to the still functioning deciduous tooth.

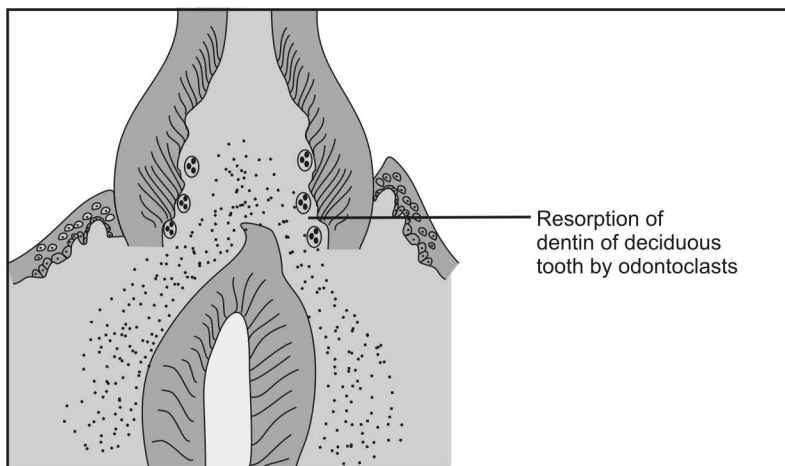


Fig. 12.9: Resorption of dental hard tissue by odontoclast

Resorption of the roots of deciduous molars often first begins on their inner surfaces because the early developing bicuspid are found between them. This resorption occurs long before the deciduous molars are shed and reflects the expansion of their growing permanent successors. However, as a result of the continued growth of the jaws and occlusal movement of the deciduous molars, the successional tooth germs come to lie apical to the deciduous molars. This change in position provides the growing bicuspid with adequate space for their continued development and also relieves the pressure on the roots of the overlying deciduous molars. The areas of early resorption are repaired by the deposition of a cementum-like tissue. When the bicuspid begin to erupt, resorption of the deciduous molars is again initiated and this time continues until the roots are completely lost and the tooth is shed. The bicuspid thus erupt in the position of deciduous molars.

Histology of Shedding

The cells responsible for the removal of dental hard tissue are identical to osteoclasts, the highly specialised cells responsible for the removal of bone, and are called odontoclasts.

Odontoclasts are readily identifiable in the light microscope as large, multinucleated cells occupying resorption bays on the surface of a dental hard tissue. Their cytoplasm is vacuolated and the surface of the cell adjacent to the resorbing hard tissue forms a 'brush' border.

Histochemically, a characteristic feature of the odontoclast is a high level of activity of the enzyme acid phosphatase. These light-microscope observations have been confirmed and extended with the electron microscope. The brush border is resolved as a ruffled border produced by extensive folding of the cell membrane into a series of invaginations 2 to 3 μm deep, with mineral crystallicities within the depths of the invaginations. The cytoplasm of the odontoclast is characterised by an exceptionally high content of mitochondria and many vacuoles, which are especially concentrated adjacent to the ruffled border. Acid phosphatase activity occurs within these vacuoles (Fig. 12.10).

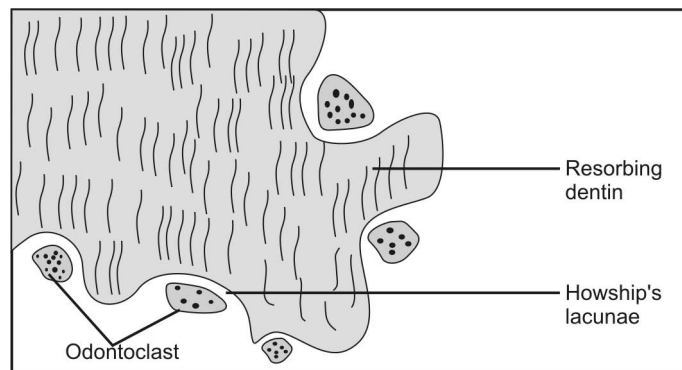


Fig. 12.10: Odontoclast activity

Odontoclasts are able to resorb all the dental hard tissues including, on occasions, enamel. When dentin is being resorbed, the presence of the tubules provides a pathway for the easy extension of odontoclast processes. Odontoclasts probably have the same origin as osteoclasts. The monocyte, circulating in the blood, originally gives rise to all the different tissue macrophages, including the osteoclast, but what is not certain is whether osteoclasts are further formed from mainly resident tissue macrophages or continuously from circulating monocytes.

Odontoclasts are most commonly found on surfaces of the roots in relation to the advancing permanent tooth. However, they have also been described in the root canals and pulp chambers of resorbing teeth lying against the predentin surface. Although their location in the pulp chamber has been disputed, the most likely reason is that different patterns of resorption exist for different teeth. For example, single-rooted teeth are usually shed before root resorption is complete; therefore odontoclasts are not found within the pulp chambers of these teeth and the odontoblast layer remains intact. In molars, however, the roots are usually completely resorbed and the crown is also partially resorbed before exfoliation. When this happens, the odontoblast layer is replaced by odontoclasts, which resorb both primary and secondary dentin. Sometimes all the dentin is removed, and the vascular connective tissue is visible beneath the translucent cap of enamel.

The process of tooth resorption is not continuous, since there are periods of rest and repair; however, in the long-term, resorption predominates over repair. Repair is achieved by cells resembling cementoblasts that lay down a dense collagenous matrix in which spotty mineralisation occurs. The final repair tissue resembles cellular cementum but is less mineralised.

Mechanism of Resorption and Shedding

Pressure from the erupting successional tooth plays a key role because the odontoclasts differentiate at predicted sites of pressure.

The finding of mineral crystallites in the depths of the ruffled border and the fact that scanning electron microscopy indicates that the collagenous matrix of the dentin becomes exposed during resorption suggest that mineral is removed first. The acid phosphatase content of the vesicles close to the ruffled border suggests that these structures are phagosomes in which breakdown of ingested material is taking place. The most likely sequence of events in resorption of dental hard tissue by the odontoclast is an initial removal of mineral followed by extracellular dissolution of the organic matrix (mainly collagen) to smaller molecules, which are then taken up by the odontoclast and degraded further.

The forces of mastication applied to the deciduous tooth are also capable of initiating the resorption.

Clinical Consideration

1. *Aberrations in eruption*—
 - a. *Delayed eruption*—caused by local or systemic factor like nutritional, genetic and endocrine deficiencies.
 - b. *Premature eruption*—Sometimes infants are born with erupted lower central incisors which should be extracted as early as possible as they prevent suckling.
2. *Teething*—It is the inflammatory response of an infant as teeth break through oral mucosa. The infant may suffer from some pain, slight fever and general malaise.
3. *Remnants of deciduous teeth*—sometimes parts of the roots of deciduous teeth are not in the path of erupting permanent teeth and may escape resorption. Such remnants, consisting of dentin and cementum, may remain embedded in the jaw for a considerable time.
4. *Retained deciduous teeth*—Deciduous teeth may be retained for a long time beyond their usual shedding schedule. Such teeth are usually without permanent successors, or their successors are impacted. They are invariably out of function. Retained deciduous teeth are most often the upper lateral incisor, less frequently the second permanent premolar, especially in the mandible, and rarely the lower central incisor. If a permanent tooth is ankylosed or impacted, its deciduous predecessor may also be retained. This is the most frequently seen with the deciduous and permanent canine teeth.
5. *Submerged deciduous teeth*—Trauma may result in damage to either the dental follicle or the periodontal ligament. If this happens, the eruption of the tooth ceases and it becomes ankylosed to the bone of the jaw. Because of continued eruption of neighboring teeth and increased height of the alveolar bone, the ankylosed tooth may be either ‘shortened’ or submerged in the alveolar bone. Submerged deciduous teeth prevent the eruption of their permanent successors or force them from their position.

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Salivary Glands

Definition of gland—A gland is a unit of structure and function, involved in the manufacture and discharge of a secretion.

Classification of Glands

- According to number of cells involved:
 - a. Unicellular, e.g. Goblet cells
 - b. Multicellular, e.g. Salivary gland
- According to size:
 - a. Major, e.g. Parotid
 - b. Minor, e.g. Mucous glands of lip
- According to morphology:
 - a. Alveolar (acinar)
 - b. Tubular
 - c. Tubulo-acinar
- According to branching of the duct:
 - a. Simple (non-branching)
 - b. Compound (branching)
- According to the presence of ducts:
 - a. Exocrine (ducts are present), e.g. Salivary gland
 - b. Endocrine (ducts are absent), e.g. Pituitary
- According to type of secretion:
 - a. Serous, e.g. Parotid
 - b. Mucous, e.g. Minor salivary gland of cheek
 - c. Mixed (sero-mucous), e.g. Submandibular
- According to damage of secretory cells at discharge:
 - a. Merocrine (no damage), e.g. Salivary glands.
 - b. Apocrine (Cells contribute part of their protoplasmic substance to their secretion), e.g. Some sweat glands.
 - c. Holocrine (there is extreme damage of the cell, secretion consists of altered cells of the gland itself), e.g. Sebaceous gland.

Classification of Salivary Glands

Salivary glands are multicellular, merocrine, exocrine glands. They may be classified according to size, location or type of secretion.

Table 13.1: Classification of salivary glands

<i>Name</i>	<i>Size</i>	<i>Location</i>	<i>Type of secretion</i>
Parotid	Major	Cheek	Pure serous
Submandibular	Major	Floor of the mouth.	Mixed (predominantly serous)
Sublingual	Major	Floor of the mouth.	Mixed (predominantly mucous)
Superior labial and inferior labial	Minor	Lip.	Mixed (predominantly mucous)
Buccal and retromolar	Minor	Cheek	Mixed (predominantly mucous)
Posterolateral palatine	Minor	Hard palate	Pure mucous
Palatine	Minor	Soft palate	Pure mucous
Glossopalatine	Minor	Glossopalatine fold	Pure mucous
Anterior lingual (Blandin-Nuhn)	Minor	Body of tongue	Mixed (predominantly mucous)
Posterior lingual (Von Ebner)	Minor	Base of tongue	Pure serous
Posterior lingual (Tonsil, lingual)	Minor	Base of tongue	Pure mucous

Structural Pattern of the Salivary Glands (Fig. 13.1)

Salivary glands consist of two main elements—

- The parenchyma- the glandular secretory tissue.
- The stroma- the supporting connective tissue.

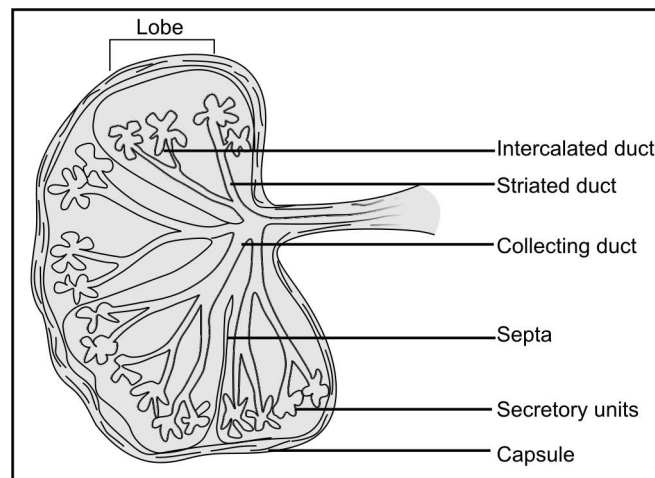


Fig. 13.1: General organization of a salivary gland

Capsule

The gland is surrounded by capsule consists mostly of collagenous tissue with few elastic and reticular fibers.

Trabeculae

From the capsule, connective tissue septae or strands traverse the glands and divide them into lobules. These septae carries blood vessels, nerves and excretory ducts. The septal connective tissue consists of mesenchymal cells, fibroblasts, plasma cells, lymphocytes and fat cells. The connective tissue of the septae spread into the lobules forming stroma for the secretory units.

Secretory Cells

Each lobule contains numerous secretory units and each unit consists of a cluster of grape-like structure (the acini) positioned around a lumen (Fig.13.2).

A secretory acinus may be serous, mucous or mixed. It is responsible for the production of primary secretion. It empties into an intercalated duct lined by cuboidal epithelium, which in turn joins a larger striated duct formed of columnar cells. Both the intercalated and striated ducts are intralobular and affect the composition of the secretion passing through them. Plasma cells (secrete the immunoglobulins) are found around the intralobular ducts. The striated ducts empty into the relatively inert excretory ducts, which carry the saliva to the mucosal surface and which may be lined near their termination by a layer of stratified squamous epithelial cells. The excretory ducts are interlobular.

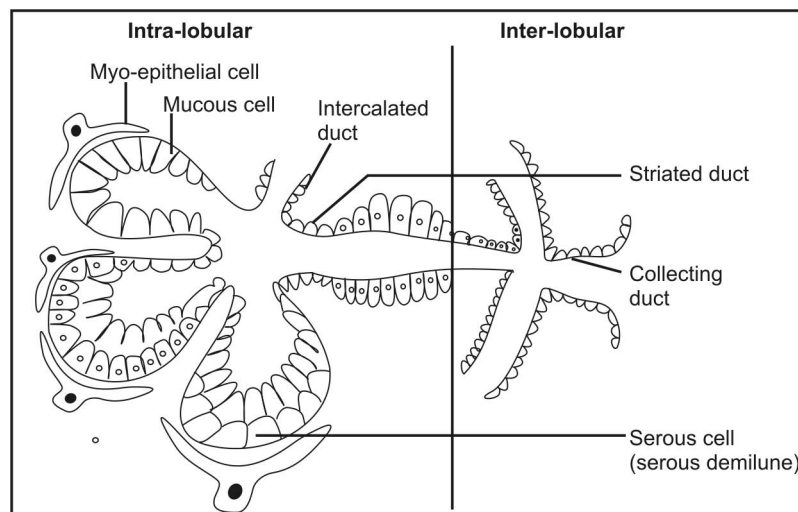


Fig. 13.2: Secretory elements of salivary gland

Mucous Acinus (Mucous Cell)

Mucous cells are large pyramidal cells with broad base resting on the basement membrane and narrow apex directed towards lumen (Fig.13.3). The nucleus is round or oval and is placed near the base. The cells form alveoli or tubules. In H and E stain they take pale blue colour and with periodic acid Schiff stain, the mucous acini appear purplish.

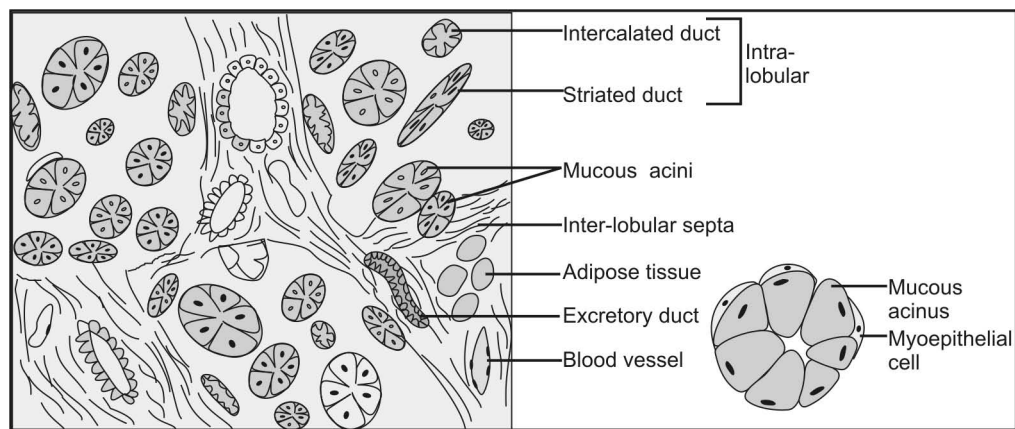


Fig. 13.3: Mucous acini

Ultrastructurally the mucous cell contains prominent Golgi complexes (which reflect the cell's increased carbohydrate metabolism) and pale, electron-lucent secretory droplets containing scattered flocculent material. In early stages of synthesis of secretory products, large amount of rough endoplasmic reticulum are present. In resting phase all cellular organelles are less conspicuous. Intercellular canaliculi are found leading to demilunes and also occur between mucous cells.

The secretory products (Mucigen) are emptied into secretory capillaries which drain into intercalated duct and then out of the gland. After mucigen is emptied into the lumen, it acquires water by virtue of its hydrophilic property and results in mucin. Certain inorganic constituents are incorporated and it changes to mucous, which is a heavy, viscous opalescent fluid. It functions as a protective lubricant.

Serous Acinus (Serous Cells) (Fig.13.4)

The serous cells are smaller. They are pyramidal in shape, with its broad base resting on a thin basement membrane and its narrow apex bordering on the lumen. The spherical nucleus is

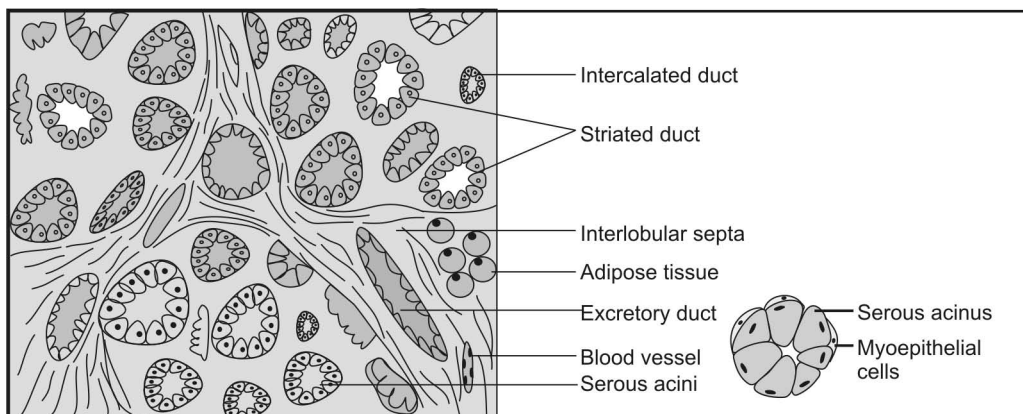


Fig. 13.4: Serous acini

located in the basal region of the cell. The distal part of the cell adjacent to the lumen contains numerous, coarse, basophilic granules, called Zymogen granules, ($1\text{ }\mu\text{m}$ in diameter) which are the precursors of ptyalin.

Ultrastructurally, the basal part of the cytoplasm is filled with ribosome studded (rough) endoplasmic reticulum (RER), a closed system of membranous sacs or cisternae. Golgi apparatus is located apical or lateral to the nucleus. Mitochondria are found throughout the cell. Many narrow canaliculi run between the cells and join the lumen. Both the canaliculi and lumen are lined by short microvilli.

The secretory proteins are synthesized by membrane-bound ribosomes, transferred to the cisternal space of RER, and migrate to the Golgi apparatus, where carbohydrate addition and other posttranslational modifications are completed, and they are packaged into secretory granules which are discharged by exocytosis at the secretory surface of cell.

Serous Crescent (Fig.13.5)

In a mixed salivary gland, the mucous cells situated more near the duct, while serous cells occupy the blind end of the acinus. In certain glands the terminals of the acini are partially surrounded by serous cells. This appears like a crescent and is called Serous Crescent of Giannuzzi or demilunes of Heidenhain.

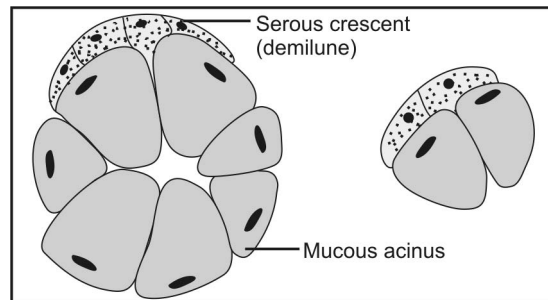


Fig. 13.5: Serous crescent

Myoepithelial Cells (Basket Cells) (Fig.13.6)

The myoepithelial cells are flattened cells found interposed between the basement membrane and the basal plasma membrane of the secretory epithelial cells and intercalated duct cells.

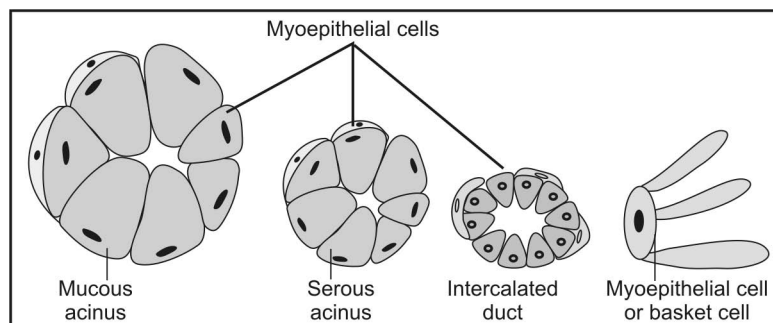


Fig. 13.6: Myoepithelial cells

There is usually one myoepithelial cell per secretory end piece (2 or 3 myoepithelial cells are also found).

The body of the cell is small, filled mostly with a flattened nucleus, four to eight cytoplasmic processes radiate from cell body to embrace the long axis of the secretory unit.

In ordinary H & E stained section under light microscope only their nuclei are visible. The typical stellate shaped cells with processes are observed by immunofluorescent techniques.

Their appearance is reminiscent of a basket cradling the secretory unit, hence the name 'basket cell'.

The ultrastructural features reveal—

- desmosomal attachments between the myoepithelial cells and the secretory cells to provide structural stability, to prevent the processes from sliding over the acinar or duct cells during contraction,
- processes filled with longitudinally oriented microfilaments, about 6 nm thick,
- small, dense, dark bodies frequently present between the thin filaments,
- other cytoplasmic organelles, located in the perinuclear region of the cell, and
- numerous micropinocytic vesicles located on the plasma membrane of the myoepithelial cells.

Function

- Myoepithelial cells are considered to have a contractile function helping to expel secretions from the lumina of the secretory units and ducts.
- They act as a support for the secretory cells, preventing overdistension as secretory products accumulate within the cytoplasm.
- They contract and widen the diameter of the intercalated ducts, thus lowering or raising their resistance to outflow.
- They may aid to rupture the acinar cells packed with mucous secretion. The myoepithelial cells are considered to be of epithelial origin because they are situated between the parenchymal cell and its basement membrane.

Oncocytes: They are large cells with small central pyknotic nucleus and abundant eosinophilic cytoplasm. They are seen frequently in the parotid and submandibular glands of older people.

Table 13.2: Difference between serous and mucous cells

<i>Serous cells</i>	<i>Mucous cells</i>
1. The cells of the serous acini are smaller and pyramidal in shape, the apex is situated towards the central narrow lumen.	1. The cells of the mucous acini are large and pyramidal, a broad base is resting on a basement membrane and narrow apex is directed towards wider lumen.
2. The nucleus is spherical and is placed in the basal third of the cell.	2. The nucleus is flattened and is placed near the base.
3. The cytoplasm is deep basophilic and contains numerous coarse basophilic zymogen granule in H and E stain.	3. In H and E-stain, mucous cell appears pale blue, the apical part stains intensely with mucicarmine stain.
4. Ultrastructurally the cells contain Golgi complex but less conspicuous than mucous cells	4. Ultrastructurally the mucous cells contain prominent Golgi cell complex and its secretory material is stored in droplets.

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<i>Serous cells</i>	<i>Mucous cells</i>
5. The serous cells have large amount of rough endoplasmic reticulum packed basally and laterally to the nucleus.	5. In resting cells, the rough endoplasmic reticulum, mitochondria are less conspicuous.
6. The interdigitations between adjacent serous cells are more.	6. The interdigitations between adjacent mucous cells are few.
7. The secretion is watery and its amylase helps to break down starch.	7. The secretion is thick and viscous. It has little or no enzymatic activity and serve mainly for lubrication and protection of oral tissues.
8. The secretion of the granule content occurs by exocytosis. The granule membrane fuses with the plasma membrane at the lumen. The opening of fused portion causes exteriorization of granule content without loss of cytoplasm.	8. The secretion of mucous droplets occur by different mechanism. The membrane of mucous droplet fuses with the apical plasma membrane. The fused membrane ruptures and the mucous droplet is discharged along with the membrane.

Ductal System

The ductal system of salivary glands is a varied network of ducts characterised by progressively smaller-diameter membranes. The network contains three classes of ducts: intercalated, striated, and terminal or excretory. The ductal system is not a simple conduit, for it actively participates in the production and modulation of saliva.

Within a lobule, the smallest ducts are the intercalated ducts which connect the terminal secretory units to the next larger ducts, the striated ducts. In the interlobular connective tissue the ducts join to form large excretory duct.

Intercalated Ducts

The secretion of the terminal end pieces passes first through the intercalated ducts (Fig.13.7). These small-diameter ducts are lined by short, cuboidal cells with centrally placed nuclei and little cytoplasm, containing some rough endoplasmic reticulum situated basally and some Golgi complexes apically. Secretory granules are occasionally found in these cells, especially in cells closest to the secretory end piece. These cuboidal cells have a few microvilli projecting into the lumen of the duct, and their lateral borders interdigitate with each other and interconnect by means of junctional complexes situated apically, as well as scattered desmosomal attachments below the junctional complexes. Myoepithelial cells, or their processes, are usually present between the basement membrane and the ductal cells. Intercalated ducts are especially prominent in salivary glands with a serous secretion and therefore occur frequently in the parotid gland.

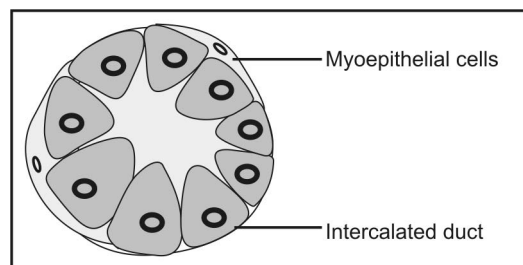


Fig. 13.7: Intercalated ducts

Striated Ducts

The intercalated duct passes into the striated duct (Fig.13.8). Striated ducts are lined by columnar cells, which have centrally placed nuclei and intensely eosinophilic cytoplasm, making the ducts clearly recognizable in H and E- stained sections. The most characteristic feature of such cells, however, is their prominent striations at the basal end of the cells, giving the ducts their name. These striations are seen by electron microscopy as particularly deep indentations of the basal plasma membrane into the cell. They also extend beyond the lateral boundaries of the cell as a series of foot processes that, in turn, possess complex secondary extensions. The lateral processes interlock in a highly complex fashion with adjacent cells and at the same time provide a large increase in the surface area of the basal plasma membrane. Many elongated mitochondria following the long axis of the folds occur in the cytoplasm between the folds. Around the nucleus are a few profiles of rough endoplasmic reticulum, along with some Golgi complexes. The apical cytoplasm often contains a few scattered vesicles, smooth endoplasmic reticulum, free ribosomes, and lysosomes. The luminal surface of the striated cell is characterised by short, stubby microvilli, and again adjacent cells are united by junctional complexes and desmosomal attachments. Occasional dark cells containing numerous mitochondria and scattered small basal cells are also present. Striated ducts are also surrounded by a number of longitudinally oriented small blood vessels.

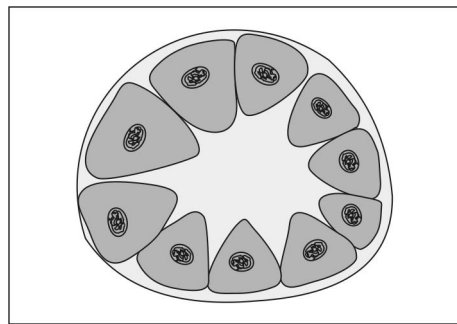


Fig. 13.8: Striated ducts

Interspersed between cells of the ductal epithelium of both intercalated and striated ducts are cells described simply as clear cells. They are thought to be of two types, one macrophage-like and the other lymphocytic, and both are involved in immune surveillance.

The specialised structure of the striated ducts implies a particular function: They modify the secretions passing through them. The fluid is characterised by an isotonic protein content, a high sodium content (hypertonic), and a low potassium content (hypotonic). As it passes along the striated duct, it changes to a generally hypotonic state. The massive infoldings of the basal plasma membrane, associated with the elongated mitochondria, are thought to reflect the sodium-pumping capacity of the cell wall in this location. Thus sodium, extracted from the cell, passes into the tissue fluid and establishes a concentration gradient between the cell and luminal fluid. Sodium therefore diffuses into the cells from the luminal fluid; at the same time active transport of potassium occurs in the opposite direction. Bicarbonate ions are also actively secreted. Because under normal conditions of flow the striated duct cells do not absorb water, these ionic changes result in the formation of a hypotonic solution.

Terminal Excretory Ducts

After passing through the striated ducts, salivary fluid is secreted into the oral cavity through the terminal excretory ducts. The histology of these ducts varies as they pass from the striated ducts to the oral cavity. Near the striated ducts they are lined by a pseudostratified epithelium consisting of tall, columnar cells (much like striated cells) admixed with small basal cells; goblet cells also occur. (Fig. 13.9). As the terminal excretory ducts approach the oral cavity, their epithelium changes to a stratified epithelium merging with that of the oral cavity at the ductal orifice. The main excretory ducts modify the final saliva by altering its electrolyte concentration, rendering it hypotonic, and perhaps also adding a mucoid component. Special eosinophilic cells, loaded with mitochondria, tend to be found in the ducts, particularly in mucosal glands. These cells are known as Oncocytes.

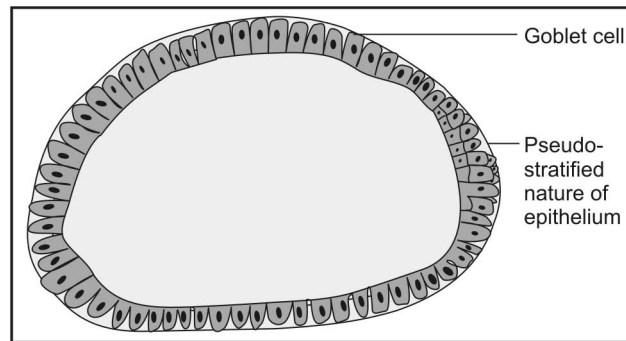


Fig. 13.9: Terminal excretory ducts

Connective tissue elements—Fibroblasts, macrophages, mast cells, occasional leukocytes, fat cells and plasma cells along with collagen and reticular fibers are embedded in a ground substance composed of proteoglycans and glycoproteins.

The vascular supply to the glands is also embedded within the connective tissue. They enter the glands along the excretory ducts and branch to follow them into the individual lobules.

The main branches of the nerves supplying the glands follow the course of the vessels, breaking up into terminal plexuses in connective tissue adjacent to the terminal portions of the parenchyma.

Table 13.3: Characteristic features of three major salivary glands

Characteristics	Parotid	Submandibular	Sublingual
Location:	Superficial portion is lying in front of the external ear and its deeper part is filling the retromandibular fossa.	It is located in the submandibular triangle behind and below the free border of the mylohyoid muscle with a small extension above mylohyoid muscle.	It lies between the floor of the mouth and mylohyoid muscle.
Main excretory duct :	Stenson's duct opens into the oral cavity on the buccal mucosa opposite the maxillary	Wharton's duct opens at a small papilla at the side of the lingual frenum on the floor of the mouth.	Bartholin's duct opens with or near the submandibular duct.

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<i>Characteristics</i>	<i>Parotid</i>	<i>Submandibular</i>	<i>Sublingual</i>
Type:	second molar. The opening is usually marked by a small papilla. It is a compound, branched, alveolar gland and purely serous.	It is compound, branched, alveolo-tubular gland. It is mixed gland with serous element predominance.	It is a compound branched tubulo-alveolar gland. It is a mixed gland with mucous predominance.
Capsule:	It is well capsulated.	It is well capsulated.	There is no capsule.
Duct system:	The intercalated ducts are long and branching. Pale-staining striated ducts are numerous.	The intercalated ducts are shorter and striated ducts are longer.	The intercalated and striated ducts are poorly developed. Mucous tubules may open directly into ducts lined with cuboidal, columnar cells without basal striations.
Serous	Absent	Frequently seen on mucous alveoli.	Occasionally seen on mucous terminal.

Saliva

Saliva is the fluid produced and secreted into oral cavity by salivary glands.

Quantity of Saliva

Pure glandular secretion is collected by special devices from the ducts. Whole saliva is obtained from the mouth, usually by expectoration. In addition to the components contributed by the glands, whole saliva contains desquamated oral epithelial cells, leukocytes, microorganisms and their products, fluid from the gingival sulcus and food remnants.

The amount of saliva secreted varies from person to person, depending on type of food taken, age, degree of mechanical stimulation, emotional condition, etc.

The total volume of saliva secreted daily by humans is approximately 750 ml of which—

60% — from submandibular gland.

30% — from parotid gland.

5% — from sublingual gland.

5% — from minor salivary gland.

pH of Saliva—varies from 5.6 - 7.6. (average is 6.8).

Composition

Water—99.5%

Inorganic component—0.2%

Organic component—0.3%

Inorganic constituents are bicarbonates, chlorides, phosphates of calcium, magnesium, potassium, bromide, iodide, fluoride, copper, oxygen and carbondioxide.

Organic constituents are—

Proteins—Glycoproteins, intrinsic salivary proteins, serum proteins like albumin and globulin, mucin;

Enzymes—ptyalin, lysozyme, lipase, phosphatase;

Blood group substances, antibodies, blood clotting factors, lipids, amino acids, urea, cholesterol.

Vitamins—pantothenic acid, riboflavin, nicotinic acid and vitamin K;

Carbohydrate—galactose, mannose, fucose, glucose;

Desquamated epithelial cells, and salivary corpuscles (resemble leukocytes, derived from gingival sulcus).

Functions of Saliva

1. *Protection*

Saliva is a lubricant. Its glycoprotein content makes it mucinous, protects the lining mucosa by forming a barrier against noxious stimuli, microbial toxins, and minor trauma.

Its fluid consistency also provides a mechanical washing action, which flushes away nonadherent bacterial and acellular debris from the mouth.

It prevents accumulation of acidogenic plaque microorganisms and hence prevents cariogenic activity of microbes.

The calcium binding proteins in saliva help to form salivary pellicle, which behaves as a protective membrane.

2. *Buffering*

The buffering capacity of saliva prevents potential pathogens from colonizing the mouth.

Plaque microorganisms can produce sugars, which are rapidly buffered and cleared by saliva, and thus prevents demineralisation of enamel.

Much of the buffering capacity of saliva resides in its bicarbonate and phosphate ions. Negatively charged residues on salivary proteins are also thought to serve as buffers; a salivary peptide, stalin, plays a significant role in raising the pH of dental plaque after exposure to fermentable carbohydrate. The ability of saliva to buffer acid is very important because saliva and plaque pH are generally lower in caries active individuals.

3. *Digestion*

Saliva is important for digestion. It provides taste activity, neutralizes esophageal contents, dilutes gastric chime, forms the food bolus, and, because of its amylase contents, breaks down starch.

4. *Taste*

Saliva is required to dissolve substances to be tasted and to carry them to the taste buds. It also contains a protein, called gustin, that is thought to be necessary for growth and maturation of the taste buds.

5. *Antimicrobial action*

Saliva contains a spectrum of proteins with antibacterial properties such as histatin. Lysozyme is an enzyme that can hydrolyze the cell walls of some bacteria. Lactoferrin binds free iron and in so doing deprives bacteria of this essential element.

Antibodies are present in saliva. The major salivary immunoglobulin, secretory IgA, has the capacity to clump or agglutinate microorganisms.

This ability, along with the cleansing action of saliva, serves to remove clumps of bacteria.

6. *Maintenance of tooth integrity*

Saliva is saturated with calcium and phosphate ions. The high concentration of these ions ensures that ionic exchange with the tooth surface is directed to the tooth. This exchange begins as soon as the tooth erupts because, although the crown is fully formed morphologically when it erupts, it is crystallographically incomplete. Interaction with saliva results in posteruptive maturation through diffusion of such ions as calcium, phosphorus, magnesium, and chloride into the surface apatite enamel crystals. This maturation increases surface hardness, decreases permeability, and heightens the resistance of enamel to caries.

7. The bleeding time of oral tissues is shorter than that of other tissues. When saliva is experimentally mixed with blood, the clotting time may be greatly accelerated.

8. *Tissue repair*—Experimental studies in mice have shown that the rate of wound contraction is significantly increased in the presence of saliva, which is thought due to the presence of epidermal growth factor in the saliva produced by the submandibular glands. The occurrence of growth is lower in human saliva.

9. Saliva excretes body metabolites (electrolytes, water and protein).

Control of Secretion

The physiologic control of salivary gland secretion is mediated through the activity of the autonomic nervous system. The release of neurotransmitters from the vesicles in the nerve terminals adjacent to the parenchymal cells stimulates them to discharge their secretory granules and secrete water and electrolytes.

The neurotransmitters interact with specific receptors located on the plasma membrane of the acinar cell.

Norepinephrine, the sympathetic transmitter, interacts with both α - and β -adrenergic receptors.

Acetylcholine interacts with the cholinergic receptor.

β -adrenergic receptors stimulate protein secretion.

α -adrenergic and cholinergic receptors stimulate low levels of protein secretion and water and electrolyte secretions.

Receptors for the peptide transmitter substance P are also present on salivary gland cells. Substance P stimulates secretion similar to that caused by α -adrenergic and cholinergic agonists.

Vasoactive intestinal polypeptide (VIP) is present in nerve endings in the salivary glands and has been shown to induce secretion by some glands.

Receptor stimulation results in increase in the intercellular concentration of “second messengers”, which trigger additional events leading to the cellular response. In the case of α -adrenergic, cholinergic, and substance P receptors, the membrane permeability to calcium-ion is increased and a marked influx of calcium-ion into the cell occurs.

The increased cytoplasmic calcium-ion concentration causes potassium-ion efflux, water and electrolyte secretion, and a low level of exocytosis.

Stimulation of the β -adrenergic receptor activates the plasma membrane enzyme adenylate cyclase, which catalyzes the formation of 3', 5'-cyclic adenosine monophosphate (cyclic AMP) from adenosine triphosphate. The increased intracellular concentration of cyclic AMP activates cyclic AMP-dependent protein kinase, an enzyme that phosphorylates other proteins, which in turn may be involved in the process of exocytosis.

Cyclic AMP may also stimulate release of calcium-ion from intracellular stores, thereby increasing its cytoplasmic concentration. Thus calcium-ion may be the common intracellular mediator for all of the receptors; the different cellular responses may reflect the different sources of calcium-ion or differing local concentration or both.

Calcium-ion may have additional effects, including stimulation of guanylate cyclase activity and an increase in the concentration of 3', 5'-cyclic guanosine monophosphate (cyclic GMP). However, the role of cyclic GMP in the secretory process has not yet been determined.

Adjacent secretory cells are joined to one another by specialized intercellular junctions called gap junctions. These junctions are permeable to ions and small molecules; thus changes in the intracellular concentration of these substances in one cell are reflected by parallel changes in the adjacent cells. Therefore physiologic stimulation probably results in a response by secretory units (acini) rather than individual cells.

The discharge of secretory granules involves translocation to the luminal cell surface and fusion of the granule membrane with the plasma membrane. The microtubules and microfilaments may act as a cytoskeletal framework or contractile mechanism for granule movement.

Clinical Considerations

1. The salivary glands are subject to a number of pathologic conditions. These include inflammatory diseases, such as viral, bacterial, or allergic sialadenitis, a variety of benign and malignant tumours, autoimmune diseases, such as Sjögren's syndrome, and genetic diseases, such as cystic fibrosis.
2. One of the most common surface lesions of the oral mucosa is a vesicular elevation called mucocele. This is produced from the severance of the duct of a minor salivary gland and pooling of the saliva in the tissues.
3. A blockage of a salivary gland duct may occur after formation of a mucous or calcified plug within the duct.
4. The major glands, especially the parotid, may become enlarged during starvation, protein deficiency, alcoholism, pregnancy, diabetes mellitus, and liver disease.
5. In conditions associated with the reduction or absence of salivary flow (xerostomia) the incidence of decay increases. Reduction in salivary flow is most often in patients with sicca syndrome or Sjögren's syndrome, after irradiation of the head and neck region, or because of the use of various therapeutic pharmacologic agents.
6. Age changes in the salivary glands, particularly prominent in the parotid, consist of a gradual replacement of parenchyma with fatty tissue. Since the parotid is the major source of serous saliva, with advancing age, patients often complain of dryness and an increase in the viscosity of saliva.

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Temporomandibular Joint

The temporomandibular joint is unique in its anatomy, histology and function. The right and left joint function as one unit. The joint is formed by mandibular fossa and articular eminence of temporal bone and mandibular condyle with articular disc interposed in between (Fig.14.1).

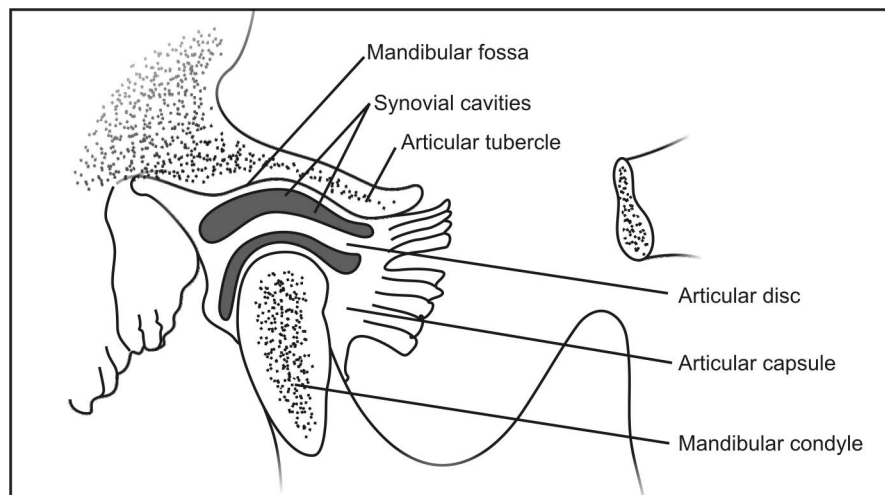


Fig. 14.1: Temporomandibular joint

In human being, the masticatory process demands that the mandible be capable of not only opening and closing movements but also protrusive, retrusive and lateral movements and combinations thereof. To achieve them, the condyle undertakes translatory as well as rotary movements. Therefore, the human TMJ is described as a synovial sliding ginglymoid joint.

Anatomy in Brief

The articular disc is interposed between the articular surfaces of the two bones. It is oval, fibrous plate. At anterior margin, fuses with the fibrous capsule, posterior border is connected to capsule by loose connective tissue, medial and lateral corners are directly attached to the poles of the condyle (Fig.14.2).

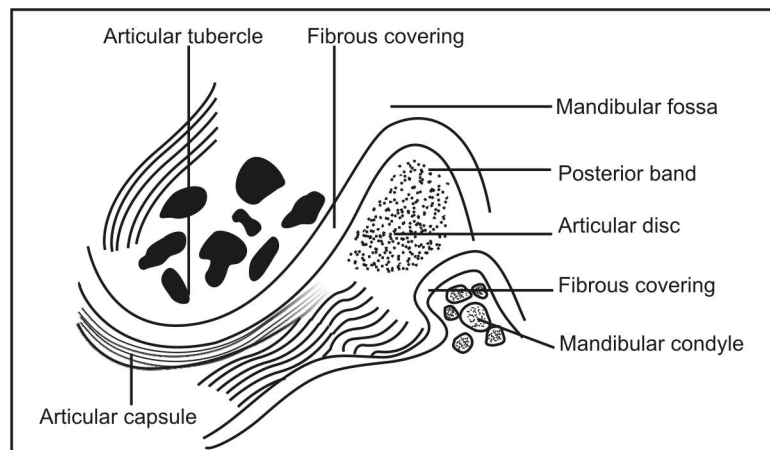


Fig. 14.2: Sagittal section through temporomandibular joint

The articular space is divided into two compartments. The lower is in between the condyle and the disc, and an upper in between the disc and temporal bone. The disc is biconcave with a thin intermediate zone, a thick anterior band, and a thick posterior band. The latter is continuous with a loose fibroelastic portion called the bilaminar zone, which is highly vascular and highly innervated. The superior stratum or lamina of the bilaminar zone attaches to the posterior wall of the mandibular or glenoid fossa and the squamotympanic suture, while the inferior stratum attaches to the back of the mandibular condyle.

Some fibers of the lateral pterygoid muscle attach to the anterior border of the disc. The disc produces a movable articulation for the condyle. In the inferior portion of the joint, rotational movement about an axis through the heads of the condyles permits opening of the jaws. This is designated as hinge movement. The superior portion of the joint permits a translatory movement as the discs and the condyles traverse anteriorly along the inclines of the articular tubercles to provide an anterior and inferior movement of the mandibular head.

The articular capsule is a fibrous sac that attaches anteriorly to the articular tubercle and posteriorly to the lips of the squamotympanic fissure and between the two attachments to the margins of the mandibular fossa and to the neck of the mandible below. It is strengthened laterally by the temporomandibular ligament. The inner aspect of the capsule is lined by a synovial membrane, which is especially well developed behind the disc. It lines the capsule in each of the two cavities but does not extend over the surfaces of the discs, the articular tubercle, or the condyle.

Histology

Bony component—The condyle of the mandible is composed of cancellous bone covered by a thin layer of compact bone (Fig.14.3). The trabeculae are grouped in such a way that they radiate from the neck of the mandible and reach the cortex at right angles, thus giving maximal strength to the condyle. The large marrow spaces decrease in size with progressing age. During the period of growth a layer of hyaline cartilage lies underneath the fibrous covering of the condyle. This cartilaginous plate grows by apposition from the deepest layers of the covering

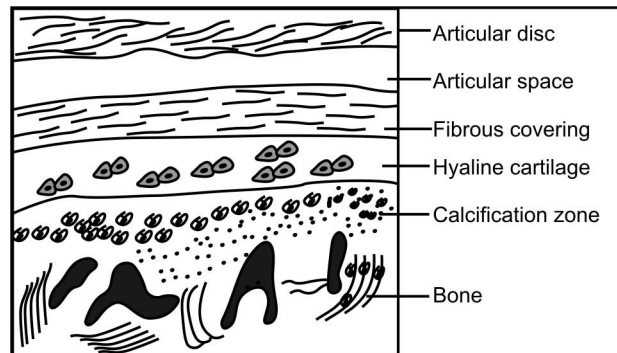


Fig. 14.3: Histology of mandibular condyle

connective tissue. At the same time its deep surface is replaced by bone. Remnants of this cartilage may persist into old age.

The roof of the mandibular fossa consists of a thin, compact layer of bone. The articular tubercle is composed of spongy bone covered with a thin layer of compact bone. In rare cases islands of hyaline cartilage are found in the articular tubercle.

Articular Fibrous Covering

The condyle as well as the articular tubercle is covered by a thick layer of fibrous tissue containing a variable number of chondrocytes. The fibrous covering of the mandibular condyle is of fairly even thickness (Fig.14.4). Its superficial layers consist of a network of strong collagenous fibers. Chondrocytes may be present, and they have a tendency to increase in number with age.

The fibrous layer covering the articulating surface of the temporal bone is thin in the articular fossa and thickens rapidly on the posterior slope of the articular tubercle. In this region the fibrous tissue shows a definite arrangement in two layers, with a small transitional zone between them. The two layers are characterized by the different course of the constituent fibrous bundles. In the inner zone the fibers are at right angles to the bony surface. In the outer zone they run parallel to that surface. As in the fibrous covering of the mandibular condyle, a variable number of chondrocytes are found in the tissue on the temporal surface. In adults the deepest layer shows a thin zone of calcification.

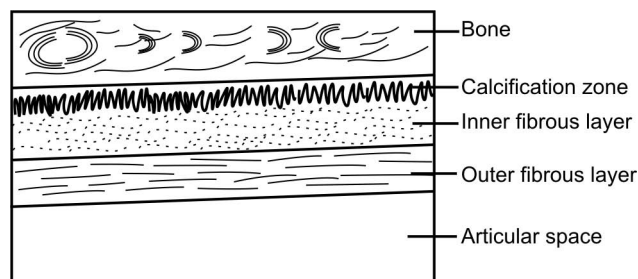


Fig. 14.4: Histology of articular tubercle

Articular Disc

In young individuals the articular disc is composed of dense fibrous tissue. The interlacing fibers are straight and tightly packed (Fig. 14.5). Elastic fibers are found only in relatively small numbers. The fibroblasts in the disc are elongated and send flat cytoplasmic wiglike processes into the interstices between the adjacent bundles.

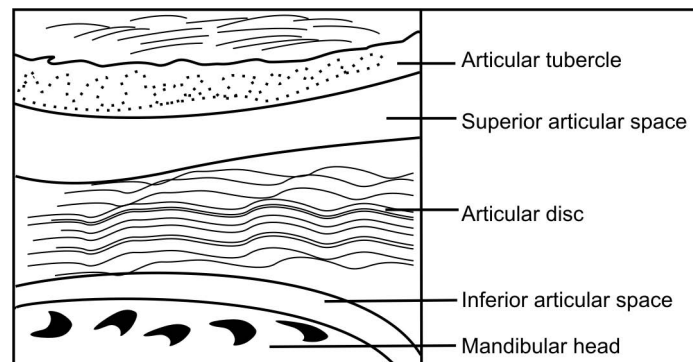


Fig. 14.5: Histology of articular disc

With advancing age, some of the fibroblasts develop into chondroid cells, which later may differentiate into true chondrocytes. The presence of chondrocytes may increase the resistance and resilience of the fibrous tissue.

The fibrous tissue covering the articular eminence and mandibular condyle, as well as the large central area of the disc, is devoid of blood vessels and nerves and has limited reparative ability.

Articular Capsule

The articular capsule consists of an outer fibrous layer that is strengthened on the lateral surface to form the temporomandibular ligament. The articular capsule is lined with synovial membrane, which folds into synovial villi and project into the joint spaces (Fig. 14.6). The synovial membrane consists of internal cells, which do not form a continuous layer but show gaps between the cells, and the subintimal connective tissue layer, rich in blood capillaries. The internal cells are of three types. The first is rich in rough endoplasmic reticulum and is called the fibroblast-like or B cell. The second type is rich in Golgi complex, contains little or no RER, and is called the macrophage-like or A cell. The third type has a cellular morphology between cell types A and B.

A small amount of a clear, straw-colored viscous fluid, synovial fluid, is found in the articular spaces. It is a lubricant and also a nutrient fluid for the avascular tissues covering the condyle and the articular tubercle and for the disc. It is elaborated by diffusion from the rich capillary network of the synovial membrane, augmented by mucin possibly secreted by the synovial cells.

Innervation and Blood Supply

Sensations from the joint structures have usually been considered proprioceptive in nature. The auriculotemporal and masseteric nerves from the mandibular branch of the trigeminal nerve

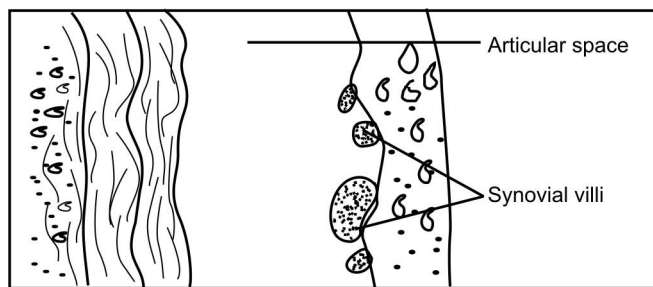


Fig. 14.6: Histology of articular capsule

supply the joint. It has been suggested that there exist a number of free, complex, and encapsulated receptors among the synovial villi of the joint capsule. The primary source of blood supply comes from the superficial temporal and the maxillary arteries of the external carotid.

Clinical Considerations

1. The thinness of the bone in the articular fossa is responsible for fractures if the mandibular head is driven into the fossa by a heavy blow. In such cases injuries of the dura matter and the brain have been reported.
2. Abnormal functional activity produces injury to the fibrous covering and the articular bones.
3. In severe trauma the articular bone is destroyed, and cartilage and new bone develop in the marrow spaces and at the periphery of the condyle. Then the function of the joint is severely impaired.
4. The term “myofascial pain dysfunction syndrome” is used to indicate a dysfunction of the temporomandibular joint.
5. Dislocation of the temporomandibular joint may take place without the impact of an external force. The dislocation of the jaw is usually bilateral and the displacement is anterior. When the mouth is opened unusually wide during yawning, the head of the mandible may slip forward into the infratemporal fossa, causing articular dislocation of the joint.

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